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1889

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UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

ON

INVERTEBRATE FOSSILS

FROM

THE PACIFIC COAST

BY

CHARLES A. WHITE

WASHINGTON
[illegible]ENT PRINTING OFFICE
1889

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
Washington, D. C., July 1, 1888.

SIR: I herewith transmit to you manuscript and drawings for a bulletin of the Survey. The manuscript embraces five articles, each under a separate subtitle. The subjects of these articles being to a greater or less extent different from one another, I have found it desirable to treat them separately; and yet, being more or less nearly related, they may be properly presented under the single general title which I have given them.

The subject of none of these articles is here treated exhaustively; but, as the field to which each pertains is a comparatively new one, it has been thought best to publish the facts which have been ascertained, together with suggestions of their probable significance, so that they may be used by those who shall pursue these or related subjects.

I beg to call your especial attention to the following facts and conclusions presented in these articles: An addition of nineteen new species and one new genus is made to the known fauna of the Chico-Téjon series of California. The existence is announced of new localities of strata referable to that series in Oregon and Washington Territory. The fauna of the Vancouver group is discussed, three new species are described, and the intimate relation of the Vancouver fauna with that of the Chico group is shown. A small, unique fauna from the coal-bearing formation of the Puget Sound basin is described, and facts are presented which indicate that this formation was deposited in an extraordinarily large estuary, which was probably contemporaneous with the Laramie sea.

The closing article relates to a small collection of Mesozoic fossils from Alaska, all of which are regarded as new, and as probably belonging to strata somewhat older than the Aucella-bearing strata of Alaska.

Very respectfully,

C. A. WHITE,
Geologist in charge of Mesozoic Invertebrate Paleontology.

HON. J. W. POWELL,
Director of the U. S. Geological Survey.

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INVERTEBRATE FOSSILS FROM CALIFORNIA, OREGON, WASHINGTON, AND ALASKA.

By C. A. WHITE.

PART I.

NEW FOSSIL MOLLUSCA FROM THE CHICO-TÉJON SERIES OF CALIFORNIA.

GENERAL REMARKS.

The fossils from the Chico-Téjon series of California described on the following pages of this bulletin were collected by Mr. H. W. Turner and Mr. J. S. Diller, respectively, both of whom have been engaged upon separate portions of the work of the U. S. Geological Survey in California for several years past. These fossils constitute additions to the already known molluscan fauna of that important series of strata which, through the labors of Gabb, Conrad, and others, has long been known to be a rich one. The fossils of this series are in many localities abundant, but they are generally in a bad state of preservation. Occasionally, however, localities are discovered where they are in better condition, from some of which the specimens herein described have been obtained; and we may reasonably expect from such favorable localities still further additions to this important transition fauna.[1]

In the year 1884 I visited California, and devoted the season to an investigation of the strata of this series at numerous localities in the field, and to a study of large collections of its fossils. As a result of these labors I became convinced that the whole series, which comprises the Chico, Martinez, and Téjon groups of the California Geological Survey,[2] is not only an unbroken one from base to top, but that it rep-

---

[1] All the hitherto published species of fossils of this series of strata are catalogued, and the greater part of them figured and described by Mr. Gabb in the two volumes of paleontology published by the State Geological Survey of California. For references to descriptions of fossils from strata equivalent with portions of this series in Oregon, Washington Territory, and British Columbia, see Parts II and III of this bulletin.

[2] Geol. Survey California, Palæontology, vol. 2, 1869, p. xiii.

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UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

# ON
# INVERTEBRATE FOSSILS
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1889

is well known that both the life and the sedimentation were frequently interrupted over large areas; and it is the evidences of these interruptions that constitute the tangible boundaries of our recognized divisions of geological time; but it is plain that neither life nor sedimentation was ever universally broken. If, therefore, it should ever be possible for us to discover strata which represent the whole genetic continuity of life during that time, it is clear that we shall then have no definable boundaries to our present recognized geological ages, periods, or epochs. This view of the case, which seems to be a wholly reasonable one, gives the greatest interest to such transition series as that of California, to which I have applied the compound name Chico-Téjon.[1] Furthermore, this series derives peculiar interest from the fact that it represents not only the transition from one epoch to another, but also from one well-recognized geological age to the next succeeding one.

DESCRIPTION OF SPECIES.

CONCHIFERA.

OSTREIDÆ.

Genus Ostrea Linnæus.

Subgenus Alectryonia Fischer de Waldheim.

OSTREA (ALECTRYONIA) DILLERI White.

PLATE I, Figs. 1, 2, and PLATE II, Figs. 1, 2.

Shell moderately large, subelliptical in marginal outline, the irregularity of which is increased by a more or less prominent and laterally extended posterior wing; both valves convex, but, as usual, the lower one more capacious than the upper; a more or less distinct depression, extending from near the beak to the posterior margin, defines the inner limit of the alate portion of the shell; the cardinal border of the alate portion long and straight, the inner surface of which presents a rather indistinctly defined flat cardinal area; ligamental groove of the lower valve short and not deep, the corresponding ridge of the upper valve often hardly perceptible. Surface of the body of the shell marked by numerous strong angular radiating ribs, which give the free margins of the valves a strongly serrate character; surface of the wing irregularly ribbed or corrugated; muscular scar large and deep.

While a large proportion of the fossil Ostreidæ which are obtained from the different geological formations possess too few salient features by which they may be satisfactorily separated into species, and sometimes even into the different recognized genera, the features of the form here described are more than usually satisfactory in this respect. It is also the only ostreid of the Alectryonia type which to my knowledge has yet been discovered in the Chico-Téjon series, while those belonging to the ordinary type of *Ostrea* are not uncommon in the strata of this series. Furthermore, this species ought to be placed among the Cretaceous types of the Chico-Téjon series, because the Alectryonia division of the genus *Ostrea* has hitherto been rarely, if ever, known in later strata than those of the Cretaceous.

---

[1] In giving a single name to the full series, I have compounded the two group names, Chico and Téjon, which were given by the California geologists to the lower and upper portions of the series, respectively.

Position and locality.—This form was discovered by Mr. J. S. Diller in strata of the Chico portion of the series half a mile south of the falls of Clover Creek, Shasta County.

PHOLADIDÆ.

Genus Zirphæa Leach.

ZIRPHÆA PLANA, sp. nov.

PLATE IV, Fig. 22.

Among the fossils collected by Mr. H. W. Turner from the Chico-Téjon strata at Martinez, Contra Costa Co., is a single valve of a shell which seems to possess the essential characters of Zirphæa. The shell is small, irregularly suboval in marginal outline; the anterior portion inflated, larger than the posterior portion, from which it is separated by a well-defined depression that extends from near the beak to the base of each valve, and also by the abrupt inflation of the anterior portion; cardinal border of the anterior portion somewhat reflexed. The shell substance of the specimen is mostly exfoliated, but remains of narrow, concentric, raised striæ are observable, which are separated by rather wide interspaces and which seem to have covered the whole surface.

Length, 14^{mm}; height, 11^{mm}.

GASTEROPODA.

ACTÆONIDÆ.

Genus Actæon Montfort.

ACTÆON INORNAT[illegible], sp. nov.

PLATE IV, Figs. 16, 17, and 18.

Shell small, subovate, spire short, its sides approximately straight; volutions six or seven in number, those of the spire moderately convex, the last one large and somewhat inflated, the distal side of each volution appressed against the next preceding one, the suture being impressed; columella bearing one prominent fold about its middle, which is fully visible only when the outer lip is broken away; surface nearly plain, but under a good lens fine revolving striæ are visible upon the lower half of the volutions of well-preserved examples.

Length, 11^{mm}; breadth of last volution, 6^{mm}.

This shell differs from *A. impressus* Gabb, from the Shasta group of California, in having only one fold upon the columella instead of two, as that species has, and also in having the surface less distinctly marked by revolving lines.

Position and locality.—The lower or Chico portion of the series, near Pence's Ranch, Butte County, where it was collected by Mr. Turner.

FISSURELLIDÆ.

Genus Vasculum, gen. nov.

Shell resembling *Capulus* or *Emarginula* in general shape, but the upper part is more or less laterally deflected; apex subcentral, directed forward, or obliquely forward, and coiled; a more or less distinct siphonal ridge with its corresponding internal groove extends from the apex to the front border of the shell, where it produces a small emargination or notch. Internal characters unknown.

The observable characters of this form seem to warrant its reference to the Fissurellidæ; but it is probable that it may have to be referred to either the Siphonariidæ or the Gadiniidæ when all its characters are known. This genus differs from other members of the Fissurellidæ in having the apex directed anteriorly, and in being more distinctly coiled. It differs from *Anisomyon* Meek in having its apex distinctly coiled, and in possessing a siphonal ridge and emargination, in which latter respects it also differs from the Capulidæ. From *Gadinia* it differs in having a plain, instead of a radiated, surface, a coiled apex, and a greater elevation.

VASCULUM OBLIQUUM, sp. nov.

PLATE IV, Figs. 19, 20, 21.

Shell suboval in marginal outline; moderately elevated, the upper portion bent to the right, so that the right side is concave vertically; left side broadly rounded; posterior and anterior sides more narrowly rounded; apex small, turned forward and slightly to the left, and closely coiled in one, or one and a half volutions; siphonal ridge narrow but somewhat prominent, the emargination at its anterior end slight. Surface marked by lines of growth, which are coarser upon the siphonal ridge than elsewhere, and curved backward, corresponding with the emargination at the front.

Transverse width at the margin, 14^{mm}; antero-posterior width, 18^{mm}; height from margin to apex, 13^{mm}.

Position and locality.—Chico Group, cañon of Chico Creek 15 miles east of Chico, Butte County, where it was collected by Mr. Diller.

STOMATELLIDÆ.

Genus Lysis Gabb.

LYSIS OPPANSUS, sp. nov.

PLATE IV, Figs. 14, 15.

Shell having the general form of the type species of the genus *Lysis*, or of *Stomatella;* the periphery of the last volution usually somewhat angulated, the spire small and slightly elevated, aperture large, inner lip broad, thickened by callus, and its surface and margin both concave. Surface marked by rounded, rugose, coarse, raised revolving striæ or small ridges, every third or fourth one of which is larger than the others; the periphery of the shell being occupied by one of the larger ones of these raised striæ or ridges increases its angular aspect, which is more apparent in some examples than others.

I was at first disposed to regard this shell as belonging to the type species as described and figured by Gabb,[1] but it differs materially in the angular character of the periphery and in the character of the surface markings, and it apparently reaches a considerably larger size.

Among his fossils from the Vancouver group on Sucia Island, Mr. Whiteaves describes and figures[2] a form under the name of *Stomatia suciensis*, together with a variety to which he gives the name of *carinifera.* He does not figure the aperture of either of them, but from his reference to the inner lip I suspect that they belong to Gabb's genus *Lysis.* The difference between the two forms which he figures is greater than one would naturally expect as a result of interspecific variation. The California specimens of the form here described also present such considerable variations as to suggest the possibility that there may be specific identity between at least a part of the California and Sucia Island forms respectively.

Position and locality.—Chico group, near Pence's Ranch, Butte County. Collected by Mr. Turner and myself.

TROCHIDÆ.

Genus Trochus Linnæus.

Subgenus Anadema H. and A. Adams.

TROCHUS (ANADEMA) GEMIFERUS, sp. nov.

PLATE IV, Figs. 8, 9.

Shell small, depressed-conical, the height being somewhat less than the greatest diameter; aperture subcircular, oblique; umbilicus small and deep; inner lip with a callus at its upper portion, which borders a part of the umbilicus, slightly thickened below, where it bears just within its outer edge a small distinct tubercle-like tooth having somewhat the appearance of a small adherent pearl. Surface finely granular, and under a lens faint indications of revolving striæ appear.

---

[1] Palæontology of California, vol. 1, 1864, p. 138, pl. 21, fig. 98.

[2] Geol. Survey Canada, Mesozoic Foss., vol. 1, 1876, p. 128, pl. 16, figs. 4, 5.

Height, 13^{mm}; greatest breadth, 16^{mm}.

The characters of this shell do not fully agree with those which H. and A. Adams assign to *Anadema*, but they correspond more nearly with that subgenus than with any other group of shells known to me.

Position and locality.—Chico group, near Pence's Ranch, Butte County. Collected by Mr. Turner.

The shell substance of the specimens from which the foregoing description is drawn is thickly burrowed by fine pores, which are apparently those of a species of *Cliona*. The burrows are all apparently simple, are perpendicular to the outer surface, and penetrate almost to the inner surface. Only a part of the shells of other species of mollusks which were found associated with this one are thus burrowed, but the borings have been detected in still other species at other localities in the same formation. In all these cases all the borings are almost microscopic, and quite uniform in character. It is no uncommon thing to find shells of the *Ostreidæ* and other mollusks in all the Cretaceous and Tertiary formations showing ravages of *Cliona*; but in all cases which I have observed those borings are much larger and usually more intricate than those which are here referred to.

Genus Stomatia Lamarck.

STOMATIA OBSTRICTA, sp. nov.

PLATE IV, Figs. 10, 11.

Shell rather small, obliquely subovate; spire short, prominent; volutions four or five in number, moderately convex, the last one large and expanded, suture impressed; aperture large, suboval, angulated posteriorly; inner lip moderately thickened; outer lip thin. Surface marked by angular revolving ridges with somewhat broad gently concave spaces between them, which are apparently marked by one or more revolving lines. Six or seven of these ridges appear upon the last volution, but only three of them upon those of the spire.

Length of the largest specimen in the collection, 20^{mm}; breadth, 15^{mm}.

The characters of this shell do not quite correspond with the usual generic diagnosis of *Stomatia*, but, so far as they are observable in these not perfectly preserved fossil specimens, they appear to agree more nearly with that than with any other published genus. It is a noteworthy fact, and one which Mr. Gabb fully recognized in his work upon the palæontology of California, that the molluscan fauna of the Chico-Téjon series contains many forms which, while closely like well known genera, present such differences as to make their reference to any of them unsatisfactory. This condition of things seems to me to be a natural consequence of the transitional character of such a fauna as that of this great series. Certain genera being recognized as characteristic of certain periods, it is natural to expect that transitional modifications of those genera should occur in transitional strata.

Position and locality.—Chico group, Little Cow Creek, Shasta County, where it was collected by Mr. Diller.

NATICIDÆ.

Genus Gyrodes Conrad.

GYRODES DOWELLI, sp. nov.

PLATE III, Figs. 8, 9.

Shell of medium size, depressed, oblique, spire slightly elevated; volutions, four or five in number, the last one much expanded, broadly rounded at the outer side and abruptly rounded and somewhat shouldered at the distal side; those of the spire, convex; suture distinct, impressed; umbilicus, somewhat narrow, deep; its border abruptly rounded and marked by numerous oblique crenulations. Somewhat similar flexuous crenulations mark the upper or distal side of the volutions near the suture, with which exception the surface is plain; aperture obliquely suboval, outer lip, thin; inner lip bordering the umbilicus, thin and concave. The striæ of growth show that the outer lip was much projected near its upper or posterior end, and that it was there abruptly rounded backward to the suture, adjacent to which it thus formed a somewhat broad notch.

Position and locality.—This specimen was collected from the Chico group near Jacksonville, Oregon, and sent to the Smithsonian Institution by B. F. Dowell, esq., in whose honor the specific name is given. Fragments apparently belonging to this species have also been detected among the California collections.

APORRHAIDÆ.

Genus Rimella Agassiz.

RIMELLA MACILENTA, sp. nov.

PLATE III, Figs. 10–12.

Shell rather small, slender; the sides of the spire gently convex, each bearing about twelve abruptly raised longitudinal varices, which extend entirely across the exposed surface of the volutions in the direction of the axis of the shell, and are sometimes continuous from one volution to the next. The varices are separated by somewhat broad, concave spaces, and the entire surface is marked by fine, uniform revolving striæ, which are only a little less distinct upon the varices than upon the interspaces. The outer lip is moderately expanded, the expansion being a little greater anteriorly than posteriorly, rounded in front, thickened at its margin, which is continuous with the right wall of the posterior canal. The inner lip is somewhat thickly covered with callus, which extends backward and forms the left wall of the posterior canal. Anterior canal short, reflexed, and only slightly projecting beyond the anterior border of the outer lip. Posterior canal long, nearly inclosed by the approaching borders of its right and left walls, the two walls together forming a ridge, which is closely adherent to the spire, and, in fully adult examples, extends from the posterior angle of the aperture nearly or quite to the apex of the spire.

The full length of an adult shell is about 25^{mm}.

Position and locality.—Chico group, about 2 miles northward from New Idria. Fresno County, where it was collected by Mr. Turner and myself.

TURRETELLIDÆ.

Genus Mesalia Gray.

MESALIA OBSUTA, sp. nov.

PLATE IV, Figs. 6, 7.

Shell small, elongate-conical, sides gently convex; volutions eight or ten in number in fully adult shells, moderately convex, the last one rounded below; suture impressed; surface of the volutions of the spire marked by seven or eight impressed revolving lines, at the bottom of which are close-set shallow pits, giving the lines the appearance of finely stitched seams. The lower convex surface of the last volution is also marked by similar lines, which are smaller and nearer together at the anterior part of that volution.

Length of an adult shell, about 22^{mm}; breadth of the last volution, about 9^{mm}.

Position and locality.—Chico group, near Pence's Ranch, Butte County, where it was collected by Mr. Turner.

MELANOPSIDÆ.

Genus Faunus Montfort.

FAUNUS MARCIDULUS, sp. nov.

PLATE IV, Figs. 12, 13.

Shell small, moderately elongate; volutions about six in number, their sides gently convex, their distal border appressed against the next preceding volution; the last volution moderately ventricose, and constituting nearly one-half the full length of the shell; aperture suboval, angular at its posterior end and ending anteriorly in a broad notch; outer lip thickened, prominent, especially its anterior portion outside the notch; callus of the inner lip moderately thick at the posterior portion, but thinner anteriorly. Surface appearing granular to the naked eye, but under a lens it presents the appearance of being shriveled or irregularly wrinkled.

Length, 8^{mm}; breadth of the last volution, 2^{mm}.

Position and locality.—Chico group, Butte County, where it was collected by Mr. Turner.

RISSOIDÆ.

Genus Ceratia H. and A. Adams.

CERATIA NEXILIA, sp. nov.

PLATE III, Figs. 13, 14.

Shell small, elongate-conical; sides of the spire slightly convex; volutions eight or nine in number, convex; suture impressed; aperture broadly suboval; outer lip thin; inner lip sinuous, and bearing only a slight coating of callus. Surface marked by numerous revolving raised lines, which are crossed at right angles by numerous linear ridges of about the same strength as the revolving lines, giving the surface a finely interlaced or reticulate appearance. On the anterior portion of the last volution the lines are finer and less prominent than upon the outer surface of the volutions, and the surface there thus loses to some extent its reticulate appearance. Upon the larger specimens supplementary revolving lines may sometimes be seen between the larger ones. No varices appear upon any of the specimens such as would suggest a reference of this to the genus *Cirsotrema*. It apparently bears considerable resemblance, however, to a form obtained by Mr. Whiteaves from the Vancouver group, on Sucia Island, to which he gave the name of *Cirsotrema tenuisculptum*,[1] and which is perhaps congeneric with it.

MURICIDÆ.

Genus Trophon Montfort.

TROPHON CONDONI, sp. nov.

PLATE III, Figs. 4, 5.

Shell moderately small; spire low, the last volution constituting much the greater part of the shell, its outer side convex above but becoming concave as it merges into the broad beak; the outer portion of the posterior side shouldered or abruptly rounded and its inner portion appressed against the preceding volution, there being a revolving depression between the outer and inner portions; aperture broadly subovate;

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[1] Geol. Survey Canada, Mesozoic Foss., vol. 1, 1876, p. 127, pl. 16, figs. 3–3c.

its two lips, meeting by the thickening of each, as the shell approaches maturity, extend back upon the penultimate volution; canal narrow, rather short, and turned a little backward and to the left; beak broad, concave upon its under side, its anterior border rounded and laciniate. Surface marked by numerous small, rough, revolving ridges, which are crossed by longitudinal ridges of similar size, giving the shell a coarsely cancellate appearance.

Length of the largest specimen in the collection, 30^{mm}; breadth of the last volution, about 22^{mm}.

The specific name is given in honor of Prof. Thomas Condon of the State University of Oregon, who has done much to show the presence of the great Chico-Téjon series in various parts of Oregon.

Position and locality.—Chico group, Little Cow Creek Valley, about eighteen miles east of Redding, Shasta County, where it was collected by Mr. Diller.

BUCCINIDÆ.

Genus Cominella Gray.

COMINELLA LECONTEI, sp. nov.

PLATE IV, Figs. 4, 5.

Shell rather small, ovoid, spire short; volutions about five in number; the last one moderately ventricose and constituting much the greater part of the shell; the distal border of each volution appressed against the preceding volution, and just forward of that border there is a broad shallow revolving depression; aperture subovate, compressed, and narrowly angular behind and ending anteriorly in a short narrow canal; outer lip thin at the edge and marked within by numerous transverse raised lines. Surface marked by numerous nearly uniform impressed revolving lines, which are visible to the naked eye, and the lens shows a similar minute line between each two of the others.

Length 21^{mm}; breadth of the last volution 13^{mm}.

These shells also show the ravages of the minute *Cliona* mentioned on page 18. The specific name is given in honor of Prof. Joseph LeConte of the University of California.

Position and locality.—Chico group, near Pence's Ranch, Butte County, where it was collected by Mr. Turner.

FASCIOLARIIDÆ.

Genus Fulgur Montfort.

FULGUR HILGARDI, sp. nov.

PLATE III, Figs. 2, 3.

Shell small for a species of this genus; spire depressed-conical; volutions five in number; those of the spire so flattened upon their outer surfaces as to form an oblique cone, the sides of which are slightly concave, and the base of which is upon the periphery of the last volution; suture indistinct; last volution large, subangular at the periphery and convex below it; beak long, slender, and only slightly flexed; aperture suboval, angular behind and ending in a long, open, moderately narrow canal in front; surface marked by numerous revolving raised coarse lines or slender ridges which disappear entirely upon the beak, and are often obscure on the spire above the periphery, especially in mature examples; the peripheral ridge, as well as the one upon either side of it, becomes sharply nodular as the shell reaches maturity.

Length from the apex to the end of the beak 37^{mm}; diameter of the last volution 20^{mm}.

This shell derives peculiar interest from the fact that although it belongs to a decidedly Tertiary type, it was found, together with many other Tertiary forms, commingled in the same matrix with such Mesozoic forms as *Ammonites chicoensis*, *Belemnites chicoensis*, *Trigonia Evansana*, *Inoceramus Whitneyi*, etc.

The specific name is given in honor of Prof. E. W. Hilgard of the University of California.

Position and locality.—Chico group, near Pence's Ranch, Butte County, where it was collected by Mr. Turner.

VOLUTIDÆ.

Genus Fulguraria Schumacher.

FULGURARIA GABBI, sp. nov.

PLATE III, Fig. 1.

Volutilithes navarroensis Gabb (not Shumard) Palæontology of California, vol. 1, p. 102, pl. 19, fig. 56.

Fulguraria navarroensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 117, pl. 15, figs. 3, 3*a*.

Shell rather large, fusiform, the greatest diameter being above the mid-length of the shell; spire conical, rather short; volutions about six in number; those of the spire gently but irregularly convex; the last volution large, moderately inflated and much elongated, sides broadly convex from front to rear, except that there is a broad, gentle, oblique, revolving depression about its middle; anterior extremity narrowed, but not forming a distinct beak, and a little deflected laterally; aperture moderately broad, angular behind, and ending anteriorly in an indistinctly defined canal; columella strong in adult shells and bearing three prominent oblique folds; surface marked by obscure longitudinal varices, which do not extend to the anterior part of the shell, and are often obsolete elsewhere. Besides these varices and the numerous fine, distinct lines of growth there are many narrow revolving ridges which are especially conspicuous upon the last volution and which sweep forward upon the anterior part of the shell. They are about eighteen in number, the spaces between them being wider than the ridges, the widest spaces being upon the broadest part of the shell. Upon this part especially these ridges become nodulous where they cross the varices, between which they are obsolete. The two or three upper ridges are smaller than any of the others, and those of the anterior part of the shell are smaller, more continuous, and therefore less nodular than those of the middle portion.

Although the foregoing description is drawn from larger examples than those of Mr. Gabb they belong to the same species which he referred to the *Volutilithes navarroensis* of Shumard, the type of which was obtained from the Cretaceous of Texas. Dr. Shumard never figured his species, and upon a late visit to his original localities in Texas I was not able to rediscover it, but after a careful reading of his description, an examination of many specimens from the Pacific coast region of the form here described, and of examples in the U. S. National Museum which I believe to be specifically identical with Shumard's *V. navarroensis*, I am of the opinion that the southern and western forms are sufficiently distinct to warrant the use of separate specific names.

While I agree with the opinion of Mr. Whiteaves[1] and of Dr. Stoliczka that this shell and its real congeners ought to be referred to the genus *Fulguraria*, I can not agree with the former and with Mr. Gabb in regarding the form here described as specifically identical with the one which was described by Dr. Shumard (op. cit.) under the name of *Volutilithes navarroensis*. It is very apparent that the two forms are closely related, but in view of their considerable differences and of the fact that the faunas to which they respectively belong are so different there seems to be sufficient reason for regarding them as distinct. The figures given by Mr. Gabb and Mr. Whiteaves respectively (op. cit.) and the one on Plate III of this bulletin all belong without doubt to the same species, although they show much variation of form. Figure 1 on Plate III of this bulletin shows a mature and more robust example than that of Mr. Gabb (op. cit.), while that of Mr. Whiteaves (op. cit.) shows a mature and still more compact example. On the other hand, the Museum examples of the southern form before referred to, while they are evidently mature, are even more slender and delicate than is indicated by Dr. Shumard's description. Even if these differences should not be properly regarded as of themselves sufficient to separate the two forms specifically, I think it is expedient to give different names to all the members of faunas which are respectively so different as are those of the Pacific and Gulf coast Upper Cretaceous until a far greater amount of knowledge concerning their correlation is obtained than we now possess.

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[1] A letter just received from Mr. Whiteaves says that now, with Tryon, he regards this form as belonging to Conrad's genus *Volutoderma*. As I have not had an opportunity to examine Conrad's type, I prefer at present to leave it in *Fulguraria*.

This species is one of the more common and characteristic shells of the Chico group, as it seems also to be of the Vancouver group. It has been found at numerous places in California, in southern Oregon, and I have lately received it from Dr. Newberry, who obtained it from the Vancouver group on Sucia Island, Washington Territory. The specimen figured on Plate III was collected by Mr. Turner from the Chico group, near Centerville, Butte County.

CANCELLARIIDÆ.

Genus Cancellaria Lamarck.

CANCELLARIA TURNERI, sp. nov.

PLATE III, Figs. 6, 7.

Shell of medium size, spire moderately elevated; beak short; volutions of the spire convex, the last one expanded and becoming obtusely angular between the outer and posterior sides, where short, more or less distinct varices appear, but they become obsolete upon both the outer and posterior sides; the outer side rounded, the posterior side flattened and forming a broad shoulder as the shell reaches maturity; aperture subovate, truncated behind, and ending anteriorly in a short canal; columella thickened and bearing three folds. Surface marked by revolving lines, which are crossed by lines of growth giving the usual cancellated appearance which is characteristic of this genus.

Length of the largest example in the collection, 31^{mm}; breadth of the last volution, 22^{mm}.

Position and locality.—Chico-Téjon series, Martinez, Contra Costa County, where it was collected by Mr. Turner.

PLEUROTOMIDÆ.

Genus Scobinella Conrad.

SCOBINELLA DILLERI, sp. nov.

PLATE IV, Figs. 1–3.

Shell of medium size, fusiform, volutions about seven in number; those of the spire irregularly convex; the last one large, elongate, and ending anteriorly in a broad beak, its greater or peripheral diameter near its upper end, concave above this peripheral portion, and broadly convex below it; aperture rather narrow, constricted and narrowly angular at its posterior end and merging into a rather short canal in front; outer lip thin, having a broad notch opposite the space between the suture and peripheral portion of the last volution, below which the margin of the lip is broadly convex; inner lip bearing three sharp prominent folds, the full prominence of which is not visible when the outer lip is entire. Surface marked by numerous coarse raised revolving lines or small ridges, which are largest about the middle, smaller below and upon the beak, and obsolete upon the concave space between the periphery and suture. The median portion of the last volution is also marked by more or less strong longitudinal varices, which end abruptly at the periphery, to which they give a more or less nodular appearance, and gradually disappear below.

The full length of an adult shell was about 45^{mm}; greatest breadth about 19^{mm}.

Position and localities.—Chico group, Little Cow Creek Valley, 18 miles east of Redding, Shasta County, where it was collected by Mr. Diller. Mr. Turner also collected it from the same group at Curry's Cañada, south of Mount Diablo.

CEPHALOPODA.

AMMONITIDÆ.

Genus Ammonites Bruguière.

AMMONITES TURNERI, sp. nov.

PLATE V, Figs. 1, 2.

Shell robust; volutions increasing rapidly in size, their transverse diameter being a little greater than the other, each volution embracing less than half the diameter of the preceding one; peripheral sides a little flattened; umbilicus moderately broad and deep, its sides being regularly rounded inward. Surface marked by transverse ribs and tubercles, which vary with the growth of the shell, being more distinct in the young or half-grown examples than in the adult state. In the former condition the transverse ribs are seen to extend from the umbilical margin continuously across the lateral and peripheral sides, except that between every two or three of these continuous ribs are supplementary ones which cross the peripheral side, but disappear before reaching the umbilical borders. The tubercles are situated in revolving rows upon these ribs. The first row is a little more than one-quarter of the diameter of the volution from its umbilical side, and the second is about the same distance laterally from the periphery. Between the outer lateral row of one side of the coil and that of the other there are upon the peripheral side of the shell three other rows of tubercles which are about equidistant from each other, the one upon the median line being less prominent than the other two. Upon the living chamber of the mature shell the two lateral rows of tubercles upon each side of the coil retain their distinctness, but the three upon the peripheral side disappear, leaving that side plain and broadly rounded.

This species is closely related to *A. Stoliczkanus* Gabb, but it differs from that form in the following particulars: The volutions increase more rapidly in size than those of *A. Stoliczkanus*: about two volutions less are visible in the umbilicus; the periphery is rounded instead of flattened; the transverse ribs are smaller and less elevated; the sides of the umbilicus are rounded instead of straight, and the greatest transverse diameter of the volutions is nearer to the umbilical than to the peripheral side. Besides this, *A. Stoliczkanus* comes from the Shasta group of the Lower Cretaceous, while this species comes from undoubted Chico strata, which belong to the extreme Upper Cretaceous. This latter fact is not necessarily conclusive, but the faunas of the two formations are very distinct from each other, and it is not to be expected that specific forms should be found to have had so great a range in time as is indicated by these two formations.

Position and locality.—Strata of the Chico group at Curry's Cañada, south of Mount Diablo, where it was collected by Mr. Turner, who found it associated with characteristic Chico forms and in whose honor the specific name is given.

PART II.

THE OCCURRENCE OF EQUIVALENTS OF THE CHICO-TÉJON SERIES IN OREGON AND WASHINGTON TERRITORY.

GENERAL REMARKS.

The area within which are found the strata of the great Chico-Téjon series and the paleontological equivalents of at least portions of it, is a very long but comparatively narrow one. The most southerly known limit of this area is near the lower boundary of the State of California, and its most northern known limit is upon Vancouver's Island, the distance between the two points being not far from seventeen degrees of latitude. All the known strata which are paleontologically equivalent with any portion of this series lie to the westward of the Sierra Nevada and the Cascade Ranges, except those which have been found in the valleys of John Day and Crooked Rivers, within a limited district east of the Cascade Range in Oregon.

It is not improbable that rocks referable to this series may yet be found still further, both southward and northward, than they are at present known to exist. Their further northward extension is suggested by certain fossils which have been published by Mr. Whiteaves from Queen Charlotte Islands.[1] One shell especially, to which he applies the name of *Periploma cuspidatum*, is apparently identical with *Meekia sella* Gabb, from the Chico group of California. Southward, however, at Todos Santos Bay, in Lower California, Mr. C. R. Orcutt has found Miocene strata resting upon those to which I have applied the name of Wallala Group,[2] and which I suppose to belong beneath the Chico Group. This indicates the absence of the whole Chico-Téjon series, at least at that locality, if not more generally. The occurrence of Chico fossils in the Vancouver Island region is discussed in Part III of this bulletin.

In consequence of the great disturbance and erosion which the strata of this series have suffered throughout the whole region in which they occur, of the extent to which they have been covered from view by surface soil and débris of erosion, and by volcanic outflows, the actual area within which they are exposed at the surface is a very irregular and a frequently interrupted one. The labors of Mr. J. S. Diller, of the Survey, in northern California, however, are showing that a large part of this irregularity of area there is due to original irregularity of the coast lines of the sea in which these strata were deposited.

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[1] Geol. Survey Canada, Mesozoic Fossils, vol. 1, part 3.

[2] See Bull. U. S. Geol. Survey, No. 22, p. 8.

Furthermore, the results of Mr. Diller's làbors, and also those of the California State Survey, indicate that it is only the lower or Chico portion of the series which occurs in northern California. That is, while the upper or Téjon portion of the series prevails in southern California, it has not been recognized in that State north of the line of the Central Pacific Railway; and yet the Chico portion prevails in a considerable part of northern California.

LOCALITIES IN SOUTHERN, CENTRAL, AND EASTERN OREGON.

Crossing over into southern Oregon, we not only find few exposures of strata referable to this series, but those of southern Oregon are referable only to the Chico portion. The best known of these localities are in the vicinity of Jacksonville. It is also the equivalents of these lower strata only which have been found east of the Cascade Range in Oregon. But Prof. Thomas Condon, of the State University of Oregon, has discovered strata at a few localities further north in that State which represent the Téjon or Eocene portion of the series. His first discovery was made several years ago in the valley of the Willamette, at the town of Albany, which discovery was announced by myself in a former bulletin of the U. S. Geological Survey.[1] Another similar discovery has been lately made by him in the vicinity of Coos Bay, Cape Arago, at the southern side of the entrance to the bay, being the locality from which he has sent to the office of the Survey a small but interesting collection of fossil mollusca. At both the localities mentioned Professor Condon found the strata to bear specimens of *Cardita planicosta.*

The specimens of this species, which he obtained in the Willamette Valley, are figured and discussed in the bulletin just cited. A part of those which come from Cape Arago are, in form and surface characters, closely like those which were found in the Willamette Valley, but a part of them are larger and in all respects closely like the variety of *Cardita planicosta,* which Profs. W. B. and H. D. Rogers described from the Eocene of Virginia under the name of *Venericardia ascia.*[2] The Cape Arago specimens show the same broadly rounded ribs and shallow, indistinctly defined grooves between them which the Virginia specimens show; and in other features, as well as in outward form, these Oregon specimens are in no essential respect different from the Virginia specimens published by the Professors Rogers.

There seems also to be no reason to doubt that these Oregon shells are specifically identical with those which Mr. Gabb described, from the Téjon group of California, under the name of *Cardita Hornii.* Mr.

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[1] The occurrence of *Cardita planicosta* Lamarck, in western Oregon: Bull. U. S. Geol. Survey, No. 18, pp. 7, 9, pl. 2.

[2] See Contributions to the Tertiary Geology of Virginia, in Trans. Am. Philos. Soc., vol. 5, n. s., p. 374, pl. 29, fig. 2.

Conrad always contended that the California shell was not specifically different from *C. planicosta*, and I see no reason for entertaining a different opinion. The feature upon which Mr. Gabb seems to have mainly relied to separate his *C. Hornii* from *C. planicosta* is the broadly rounded ribs which both the Cape Arago and Virginia specimens also show. While I have been slow to admit the specific identity of any of the fossils of the Chico-Téjon series with any which occur in either the Cretaceous or Tertiary strata of the eastern part of the continent, I think there are no substantial reasons for regarding these Carditas of the Pacific coast as specifically different from those of the Atlantic coast, which are universally regarded as identical with *C. planicosta* Lamarck.

The following is a list of the species which have been recognized in the small collection which Professor Condon sent from Cape Arago: *Nucula truncata* Gabb, *Cardita planicosta* Lamarck, *Meretrix uvasana* Conrad, *Naticina obliqua* Gabb, *Turritella uvasana* Conrad, *Fusus californicus* Gabb, *Perissolax Blakei* (Conrad) Gabb. It will be seen by reference to the California reports that all these species, assuming that the *Cardita planicosta* of Cape Arago is identical with *C. Hornii*, are characteristic species of the Téjon group, and that no Cretaceous types occur among them.

From all the information which I have been able to gather it seems that this western form of *Cardita planicosta* occurs only in the upper portion of the Téjon group and its equivalents; that is, all the known facts which relate to the fauna of the Chico-Téjon series seem to indicate that all the Cretaceous types of the series had passed away before the introduction of *Cardita planicosta* into those western waters.

Whatever may have been the case as regards the time of introduction and extinction of those forms, respectively, it is clear that if we use the commonly accepted divisions of Cenozoic time at all, that portion of the series which bears *Cardita planicosta* ought to be regarded as of Eocene age, as Mr. Conrad and Professor Heilprin have contended. And if the equivalents of those later strata which are found in other parts of the Pacific coast region are referred to the Téjon group, the reason for doing so is that they bear characteristic Téjon species as well as recognized Eocene types. It is for this reason that I refer all the Eocene strata which have been recognized as such in Oregon and Washington Territory by their marine invertebrate remains to the Téjon epoch.

LOCALITY NEAR DWAMISH RIVER, WASHINGTON TERRITORY.

This locality is known to me only by a small collection of fossils which were sent to the Smithsonian Institution some years ago by Mr. Theodore Blatte. Most of the specimens are labeled as coming from "near the mouth of Dwamish River" and "Fossil Bluff, Dwamish River." As the distance in a straight line from the outlet of Dwamish Lake to the mouth of Dwamish River is not more than a dozen miles, the district within which these fossils have been found is seen to be a small one.

This locality is of considerable interest, aside from the information it furnishes as to the geographical distribution of the Téjon strata, because of the probable relation of the strata there to those of the Puget group, which is discussed in the fourth article of this bulletin. The following is a list of the species which have been recognized in this small collection: *Cylichna costata* Gabb, *Conus Hornii* Gabb, *Lunatia nuciformis* Gabb, *Leda protexta* Gabb, *Euspira alveata* (Conrad) Gabb, *Fusus diaboli* Gabb, *Turritella uvasana* Gabb, *Tellina* ——— ?. The specimens are not in a good state of preservation, but the above identifications have been made with a good degree of satisfaction. By reference to the California reports it will be seen that all seven of those which are specifically named in the above list are known to occur in the Téjon group. Besides this no traces of any Cretaceous types are found among them, and the strata which bear these fossils are therefore referred to the upper or Téjon portion of Chico-Téjon series.

When these formations in Oregon and Washington Territory come to be examined with that care which Mr. Diller is devoting to their equivalents in California it can not be doubted that many more localities will be discovered where their strata are exposed; and that much will be learned concerning their relations to other formations. But at present little or nothing is known of the equivalents of the Chico-Téjon series in Oregon and Washington Territory except what is referred to in the foregoing paragraphs, and what has been published concerning the Vancouver Group and its fossils, for reference to which the third article of this bulletin may be consulted.

LOCALITY NEAR ASTORIA, OREGON.

There is, however, one locality on the Columbia River, near Astoria, that deserves to be mentioned in this connection. Nearly forty years ago Mr. Conrad published some fossils from that locality as of Miocene age, a part of which are exceedingly like species that are now known to characterize the Chico-Téjon series.[1] There is apparently no reason to doubt that a large part of the species figured and described in the second work cited are really of Miocene age; but it is the species which are published in the first quoted work, and in part republished in the second, concerning the Miocene age of which doubt is felt. The true Miocene fossils appear to have been collected by members of the Exploring Expedition, while the collection of those published in the American Journal is credited by Mr. Conrad to J. K. Townsend. Mr. Conrad's descriptions of Mr. Townsend's fossils are brief and mostly unsatisfactory, but his wood-cut figures are good; and they represent forms that have not to my knowledge been elsewhere recognized among the Miocene fauna of the Pacific coast.

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[1] See Am. Jour. Sci., 2d ser., vol. 5, 1848, pp. 432, 433, with 15 wood-cuts; also Wilkes's Expl. Exped., vol. 10, pp. 722–729, pl. 17–20, and remarks by Dr. Newberry in Pacific Railroad Reports, vol. 6, part 2, p. 25.

Attention may be called especially to four or five of the species figured in the American Journal. For example, the *Nucula divaricata* of Conrad differs, if at all, from *N. truncata* Gabb only in the asserted rounding, instead of the truncation of the posterior ("anterior") extremity; and yet one of Mr. Conrad's figures shows such a truncation. The *Mactra albaria* of Conrad is exceedingly like *M. Ashburneri* Gabb. The *Loripes paralis* of Conrad recalls *L. dubia* Gabb. The *Pyrula modesta* of Conrad is possibly identical with *Ficus ? cypræoides* Gabb; and the Survey collections contain specimens of *Solen* from the Téjon group of California which closely resemble Conrad's figure of *S. curtus*. Besides this, the *Aturia angustatus* of Conrad, from Astoria, is much like *A. Mathewsoni* Gabb of the Téjon group of California; and the presence of that genus in the Miocene strata seems out of place.

These similarities suggest at least the possibility that in the vicinity of Astoria both Miocene and Chico-Téjon strata occur.

PART III.

CRETACEOUS FOSSILS FROM VANCOUVER ISLAND REGION.

GENERAL REMARKS.

Prof. J. S. Newberry, of Columbia College, New York, has placed in my hands for investigation a collection of Cretaceous fossils from some of the small islands at the southern end of the Gulf of Georgia, adjacent to Vancouver Island. The islands from which these fossils were obtained are three in number, and are known by the names of Sucia, Waldron, and Sheep Jack, respectively. These fossils all belong to one and the same formation, as the identity of a large proportion of the species collected upon each of the islands demonstrates. The formation which they represent is also identical with the coal-bearing formation at Comox[1] and Nanaimo, on Vancouver Island, from which several authors[2] have obtained collections of fossils for publication, and which I shall designate as the Vancouver group. Although this formation is paleontologically equivalent, at least in large part, with the Chico portion of the Chico-Téjon series of California, as has been indicated by Meek, Gabb, Whiteaves (op. cit.), and by Professor Whitney,[3] I prefer to use the name Vancouver group as a local name for those strata which occur in the Vancouver Island region; and still retain the name Chico group for the California strata, which the geologists of that State applied to them.

The close relation of the Vancouver group to the Chico group of California is shown conclusively by the large number of species which are now known to be common to both. Mr. Whiteaves has identified (op. cit.) thirty-one Chico species among his collections from the Vancouver group; and in addition to these I have recognized about twenty species in Professor Newberry's collections from the latter group which are well known to occur in the Chico group of California. This makes no less than fifty species which are now known to be common to both the Chico and Vancouver groups, or about half of all the species which have yet been obtained from the latter group. As other species come to be discovered, it is not to be expected that the faunal relations between the strata of the northern and southern regions will be found to be materially different from what it now appears.

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[1] "Koomooks," "Komooks," and "Comax" of different authors.

[2] Meek, Trans. Albany Institute, vol. 4, 1857, pp. 37–49; Shumard, Trans, St. Louis Acad. Sci., vol. 1, 1858, pp. 120–125; Meek, Proc. Acad. Nat. Sci. Phila., vol. 13, 1861, pp. 314–318; Gabb, Palæontology of California, vol. 1, 1864; vol. 2, 1869; Meek, Bull. U. S. Geol. Survey Terr., vol. 2, 1876, pp. 351–374, pl. I-V; Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, part 2, 1879.

[3] Palæontology of California, vol. 2, p. xiv.

The following is a list of the recognized species contained in the collections sent by Professor Newberry, which constitute the basis of the present article:

List of fossils.

Name of species.	Locality where found.				
	Sucia Island.	Sheep Jack Island.	Waldron Island.	Vancouver Island.	California.
Rhynchonella ——?	+	......	......	......	......
Ostrea ——?	......	......	+	......	......
Anomia vancouverensis Gabb	......	......	+	......	......
Perna excavata, sp. nov	+	+	+	......	......
Inoceramus vancouverensis Shumard	+	+	......	+	+?
Mytilus pauperculus Gabb	......	+?	......	......	+
Cucullæa truncata Gabb	+	......	......	......	+
Grammatodon vancouverensis Meek	+	......	......	+	......
Axinæa sagittata Gabb	+?	......	......	......	+
Trigonia Evansana Meek	+	......	......	+	+
Crassatella tuscana Gabb, sp	+	......	+	+	+
Clisocolus dubius Gabb	+	......	......	......	+
Clisocolus cordatus Whiteaves	+	+	......	+	......
Meretrix uvasana Conrad	+	+	......	......	+
Cyprimeria lens Gabb	......	......	+	......	+
Mactra Ashburnerii Gabb	+	......	+	+	+
Pholadomya subelongata Meek	+	......	+	+	+?
Anatina sulcatina Shumard	+	......	......	......	......
Teredo suciensis Whiteaves	+?	......	......	......	......
Dentalium Cooperi Gabb	+?	......	......	......	+
Cinulia obliqua Gabb	+	+	......	......	+
Margarita ornatissima Gabb	+	+	......	......	+
Scalaria Mathewsoni Gabb	......	+	......	......	+
Natica?	......	+	......	......	......
Lunatia Shumardiana Gabb	+	......	......	......	+
Gyrodes Conradiana Gabb	+	+	......	......	+
Vanikoropsis suciensis, sp. nov	+	......	......	......	......
Perissolax brevirostris Gabb	......	+	......	......	+
Fusus Kingi Gabb	......	+	......	......	+
Fulguraria Gabbi White	+	+	......	......	+
Baculites chicoensis Trask	+	+	......	......	+
Ammonites Newberryanus Meek	+	......	......	+	+
Ammonites Maclurii, sp. nov	+	......	......	......	......

The first three columns of the foregoing table indicate the respective islands upon which Professor Newberry's collections were made, and the occurrence of the respective species upon them. In the fourth column the occurrence of certain of the species upon Vancouver Island is indicated, the reference in these cases being made mainly on the authority of Mr. Meek, but in part upon that of Mr. Whiteaves. The extreme right-hand column indicates which of the species of the list are now known to occur in the Chico group of California. For reference to other Chico species which occur in the Vancouver group, the works of Meek, Gabb, and Whiteaves, before cited, may be consulted.

It is an interesting fact that none of the species which in California specially characterize the upper portion of the Chico-Téjon series have yet been discovered in any of the strata of the Vancouver Island region. It is also true that only at a very few of the localities north of central California, where strata belonging to that great series are known to occur, have any of the species which are characteristic of its upper portion been found. The discovery, however, of some of the characteristic fossils of the upper portion of the series at a few localities in Oregon and Washington Territory, which have been especially discussed in the Part II of this bulletin, indicates that the upper as well as the lower portion of the series was originally deposited in this northern, as well as in the California portion of the Pacific Coast region. Still it is not improbable that the upper portion of the series failed to be deposited in a part of that northern region where strata of the lower portion are now found, in consequence of an upward movement of the sea bottom before the series was completed.

Two of the species of the foregoing list are recognized as new. These are described on the following pages and figured, together with a few of their previously known associates, on accompanying plates. As remarks upon each of the species which are already published are desirable, I have arranged them in the form of an annotated list, in which the descriptions of the new forms occur.

ANNOTATED LIST AND DESCRIPTION OF SPECIES.

BRACHIOPODA.

RHYNCHONELLIDÆ.

Genus Rhynchonella Fischer de Waldheim.

RHYNCHONELLA ———?

Among the fossils obtained upon Sucia Island is an imperfect specimen of a certain species of *Rhynchonella*. The specimen shows the general form and the fibrous shell texture so well that I have no doubt as to its generic relations; but it is too imperfect for specific description. The specimen is mainly interesting because of the comparative rarity of brachiopod remains in strata of this geological age.

CONCHIFERA.

OSTREIDÆ.

Genus Ostrea Linnæus.

OSTREA ———?

Numerous imperfect specimens of *Ostrea* were found upon Waldron Island. They belong to the typical section of the Ostreidæ, the fossil shells of which especially have usually too few distinguishing characters to enable one to give a satisfactory specific diagnosis, even when the specimens are perfectly preserved.

ANOMIIDÆ.

Genus Anomia Linnæus.

ANOMIA VANCOUVERENSIS Gabb.

Anomia vancouverensis Gabb. Palæontology of California, vol. 2, p. 202, pl. 33, fig. 102.
Anomia vancouverensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1; part 2, p. 175, pl. 21, figs. 5 a-d.

Among the fossils collected upon Waldron Island are some specimens of *Anomia*, which one can hardly doubt are specifically identical with the form Mr. Gabb and Mr. Whiteaves obtained from Vancouver Island, and which they published in the works above cited.

AVICULIDÆ.

Genus Perna Bruguière.

PERNA EXCAVATA, sp. nov.

PLATE VII, Fig. 1.

Among the fossils from all three of the islands upon which Professor Newberry's collections were made are imperfect specimens of a species of *Perna.* The greater part of the shell substance is exfoliated from all the specimens, so that they are mostly left in the condition of casts of the interior. Still the specimens indicate a well-marked species, possessing certain prominent features. The shell is moderately large; the greatest thickness, when both valves are together, a little above the mid-height and close to the front; beaks strong and projecting much forward; the hinge is long and its cartilage pits are numerous; posterior border broadly convex; the basal border usually a little straightened so as to give that part of the shell a truncated appearance. The anterior part of each valve is abruptly inflexed so that the front of the shell is strongly concave transversely, and also longitudinally, the latter concavity extending from the beaks nearly to the base of the shell. The largest example in the collection measures about 80^{mm} in length.

Genus Inoceramus Sowerby.

INOCERAMUS VANCOUVERENSIS Shumard.

Inoceramus vancouverensis Shumard, Trans. St. Louis Acad. Sci., vol. 2, p. 123.
Inoceramus vancouverensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, part 1, p. 170, pl. 20, figs. 4–4*b*.

The collections from Sucia and Sheep Jack Islands contain specimens of *Inoceramus* which doubtless belong to the form to which Dr. Shumard (op. cit.) gave the specific name *vancouverensis.* No less than five species of this genus have been recognized by different authors among the collections which have been made from the coal-bearing Cretaceous formation of the Vancouver Island region, namely, *I. vancouverensis* Shumard, *I. Cripsii* var. *subundatus* Meek, *I.* ——— ? Meek, *I. mytilopsis* (Conrad) Whiteaves, and *I. undulato-plicatus* (Roemer) Whiteaves. While our present knowledge of the correlation of the Cretaceous formations of Texas, aside from intrinsic evidence, makes it unlikely that Mr. Whiteaves[1] is correct in referring the last-named form to Roemer's Texas species, it is clearly different from any of the other recognized species of *Inoceramus* of the Vancouver Island Cretaceous. The other forms, however, not excepting the one which Mr. Whiteaves referred to the *I. mytilopsis* of Conrad, I regard as belonging to one and the same species.

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[1] A letter from Mr. Whiteaves expresses present doubt in his own mind as to the identity of the Vancouver Island and Texan forms.

After examining numerous specimens of *I. Whitneyi* Gabb, from the Chico Group of California, I am of the opinion that this form also belongs to that Vancouver Island species.

Every one who has studied the fossil forms of *Ostrea*, *Anomia*, and *Inoceramus* knows how difficult it is, when he has large collections of specimens, to make satisfactory specific determinations or identifications. Experience like this has satisfied me that the differences between the shells of *Inoceramus* from the Chico group of California and the equivalent strata of the Vancouver Island region, which have just been referred to, and which certainly all belong to one general type, are not too great to be regarded as only the result of interspecific variation. Furthermore, all these forms come from strata which clearly belong to one and the same epoch, are associated with other species which are identical in different localities, and in some cases the specimens of *Inoceramus* which have been referred to different species have been found commingled in the same matrix.

In consequence of the great difficulty which is experienced in defining species of *Inoceramus* within the range of the respective types or sections into which the genus may be divided, I am not quite satisfied as to what name ought to be retained for the Pacific coast form. Many of the specimens are closely like the form which in the Cretaceous strata of the more eastern parts of the continent is usually referred to the *I. Cripsii* of Mantell, but as the western Cretaceous fauna as a whole is so different from the eastern one, I hesitate for the present to refer the western specimens to that species. I therefore for the present retain Dr. Shumard's name, which was the first to be applied to the western form.

MYTILIDÆ.

Genus Mytilus Linnæus.

MYTILUS PAUPERCULUS Gabb ?.

Mytilus pauperculus Gabb, Palæontology of California, vol. 1, p. 183, pl. 25, fig. 165.

A few imperfect specimen of a *Mytilus* are contained in the collection made upon Sheep Jack Island, which probably belong to the *M. pauperculus* of Gabb.

ARCIDÆ.

Genus Cucullæa Lamarck.

CUCULLÆA TRUNCATA Gabb?.

Cucullæa truncata Gabb, Palæontology of California, vol. 1, p. 196, pl. 25, fig. 182.

Cucullæa (Idonearca) truncata Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, part 2, p. 165, pl. 19, figs. 2, 2*a*.

The collection from Sucia Island (whence also Mr. Whiteaves obtained some of his specimens), contains some examples of *Cucullæa*, which I refer provisionally to *C. truncata* Gabb. The Sucia Island specimens, however, in both Professor Newberry's and Mr. Whiteaves's collections, are larger than those of Mr. Gabb.

Genus Axinæa Poli.

AXINÆA SAGITTATA Gabb ?.

Axinæa sagittata Gabb, Palæontology of California, vol. 1, p. 197, pl. 31, fig. 267*a*.

The collection from Sucia Island contains specimens of a species of *Axinæa* which seem to agree too nearly with *A. sagittata* Gabb to warrant any other reference. The surface of none of the specimens, however, shows the peculiar sagittate markings which suggested the specific name to Mr. Gabb. Still the same remark is applicable to the greater part of the examples from localities in California which I have seen.

Genus Grammatodon Meek.

GRAMMATODON VANCOUVERENSIS Meek.

Grammatodon vancouverensis Meek, Bull. U. S. Geol. Survey Terr., vol. 2, p. 356, pl. 3, fig. 5.

A single example from Sucia Island seems to belong to this species; but it does not show the character of the hinge.

TRIGONIDÆ.

Genus Trigonia Bruguière.

TRIGONIA EVANSANA Meek.

Trigonia Evansana Meek, Trans. Albany Institute, vol. 4, p. 42.
Trigonia Evansana Meek, Bull. U. S. Geol. Survey Terr., vol. 2, p. 359, pl. 2, fig. 7.
Trigonia Evansana Gabb. Palæontology of California, vol. 1, p. 189, pl. 25, fig. 177.

This is one of the most characteristic species of the Chico group of California and its equivalents in Oregon and Washington Territory. Specimens of it are in Professor Newberry's collection from Sucia Island.

CRASSATELLIDÆ.

Genus Crassatella Lamarck.

CRASSATELLA TUSCANA Gabb, sp.

PLATE VI, Figs. 2, 3, and 4.

Astarte tuscana Gabb, Palæontology of California, vol. 1, p. 179, pl. 30, fig. 257.
Astarte cardinioides Whiteaves, Rept. Prog. Geol. Survey Canada for 1873–'74, p. 267.
Astarte vancouverensis Whiteaves, ibid., 267.
Astarte Conradiana var. tuscana Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 160, pl. 18, fig. 6.
Compare *A. Conradiana* Gabb, Palæontology of California, vol. 1, p. 178, pl. 24, fig. 161.

Shell irregularly subelliptical in marginal outline; valves moderately and somewhat regularly convex; dorsal border greatly convex and sloping downward and backward from the beaks; posterior border more or less distinctly truncating the shell obliquely, and then abruptly rounding to the basal border, which is broadly convex; front obliquely truncated above by the lunular depression and narrowly rounded below; umbones slightly elevated; beaks depressed, approximate, situated near the anterior end; lunule small, somewhat deeply impressed; escutcheon long and narrow, lanceolate, moderately deep, and its border well defined; cardinal tooth of the right valve strong, triangular, and placed just beneath the beak. Besides this characteristic tooth in the right valve there is an incipient one at the posterior side of the cartilage pit, and another upon the margin of the lunule, in front of the anterior dental pit; the two cardinal teeth of the left valve well developed; the lateral tooth of each valve strong, of the usual character in *Crassatella*, and extending the full length of the escutcheon; cartilage pit moderately large; the free margins of the valves crenulate internally. Surface marked by strong concentric lines and undulations of growth.

Length, 38^{mm}; height, 27^{mm}. This is the average size of the specimens from which the foregoing description is drawn; but there are some examples in the collection made upon Waldron Island, which probably belong to this species, and which reach a length almost twice as great as the others.

There seems to be no reason to doubt that this shell is identical with Gabb's *Astarte tuscana*, but yet this determination is made upon the external form alone, because Mr. Gabb neither mentions nor figures any internal characters. Neither does he mention any external ligament, which his positive reference of the shell to *Astarte* would imply he had seen. It may be mentioned, however, that the escutcheon is so narrow and clearly defined as to greatly resemble the seat of a large external ligament.

It is possible that Gabb's *Astarte Conradiana* is identical with his *A. tuscana*, as is stated by Mr. Whiteaves (op. cit.); but that question can not be satisfactorily settled without reference to Gabb's type specimens, which I have never seen. And even these would probably be insufficient, because none of them seems to have shown any of the hinge characters. These characters were imperfectly shown by Mr. Whiteaves's specimens, which apparently led him to continue the reference of the shell to *Astarte*. Our specimens, however, show it to possess the typical hinge of *Crassatella*.

The specimens of this form which are contained in Professor Newberry's collection come from Sucia and Waldron Islands.

LUCINIDÆ.

Genus Clisocolus Gabb.

CLISOCOLUS DUBIUS Gabb.

PLATE VI, Figs. 5-7.

Loripes dubius Gabb, Palæontology of California, vol. 1, p. 177, pl. 24, figs. 170, 171.
Clisocolus dubius Gabb, Palæontology of California, vol. 2, p. 189, pl. 30, fig. 87.
Clisocolus cordatus Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 157, pl. 18, figs. 3-3*b*.

The collection from Sucia Island contains some specimens which agree well with the description and figures of Mr. Gabb as first published by him under the generic name of *Loripes*. The figures on Plate VI are drawn from one of the best of these examples, and they are there given for comparison with those of the form next described, which I am disposed to regard as a distinct species.

CLISOCOLUS CORDATUS Whiteaves.

PLATE VI, Figs. 8, 9.

Clisocolus cordatus Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 157 pl. 18, figs. 3-3*b*.
Sphæriola? cordata Whiteaves (not Meek and Hayden), Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 157, pl. 18, figs. 3-3*b*.
Clisocolus dubius Whiteaves (not Meek and Hayden), Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 157, pl. 18, figs. 3-3*b*.

The following is Mr. Whiteaves's description of this species, from specimens which he obtained from Vancouver and Sucia Islands:

> Shell globose, very gibbous, especially in the umbonal region, higher than long, thickness through the valves about equal to the height. Sides and base rounded, the latter a little flattened; umbones broad, tumid elevated and approximate; beaks placed a little in advance of the middle, subspiral, their apices divergent and curving outwards; no distinct lunule or posterior area.

It is possible that *Clisocolus dubius* and *C. cordatus* belong to one and the same species, but the great differences presented by the two examples which are figured on Plate VI seem to warrant their reference to different species. While I retain for the present the specific name which has been applied to the last-mentioned form by Mr. Whiteaves, I do not agree with him in regarding it as specifically identical with the *Sphæriola? cordata* of Meek and Hayden, even if it should appear that the last-named form really belongs to the genus *Clisocolus* instead of *Sphæriola*.[1]

It is not improbable that this form ought to be separated under a new generic name, but I am not now sufficiently acquainted with its hinge and internal characters to give a satisfactory generic diagnosis.

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[1] A letter just received from Mr. Whiteaves says that he is now "convinced that this shell is specifically distinct from *Sphæriola cordata* M. and H., from *S. endotrachys* Meek, and probably also from *Clisocolus dubius* Gabb." He also agrees with my suggestion that it would be well to give it a new generic name.

The specimen of this form which is figured on Plate VI came from Sucia Island; but the collection from Sheep Jack Island also contains specimens which doubtless belong to the same form.

VENERIIDÆ.

Genus Meretrix Lamarck.

MERETRIX UVASANA Conrad.

Meretrix uvasana Conrad, Pacific Railroad Reports, vol. 5, p. 320, pl. 11, fig. 3.
Meretrix uvasana Gabb. Palæontology of California, vol. 1, p. 16, pl. 30, fig. 248.

The collections from Sucia and Sheep Jack Islands contain specimens which agree well with the figures and descriptions given by Mr. Conrad and Mr. Gabb in the works above cited.

Genus Cyprimeria Conrad.

CYPRIMERIA LENS Gabb sp.

Meretrix lens Gabb, Palæontology of California, vol. 1, p. 164, pl. 22, fig. 143.
Cyprimeria lens Whiteaves, Geol. Survey Canada, Mesozoic Fossils, p. 152, pl. 17, figs. 15, 15*a*.

A single example of this form occurs in the collection from Waldron Island.

MACTRIDÆ.

Genus Mactra Linnæus.

MACTRA ASHBURNERI Gabb.

Mactra Ashburneri Gabb, Palæontology of California, vol. 1, p. 153, pl. 22, fig. 127.
Cymbophora Ashburneri Gabb, Palæontology of California, vol. 2, p. 181.
Cymbophora Ashburneri Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 141, pl. 17, fig. 8.

Specimens of this species were obtained upon Sucia and Waldron Islands. It seems to be as common in the Vancouver group as in the Chico of California.

PHOLADOMYIDÆ.

Genus Pholadomya Sowerby.

PHOLADOMYA SUBELONGATA Meek.

Pholadomya subelongata Meek, Trans. Albany Inst., vol. 4, p. 44.
Pholadomya subelongata Meek, Bull. U. S. Geol. Survey Terr., vol. 2, p. 362, pl. 2, figs. 1, 1*a*.
Pholadomya royana Whiteaves (not d'Orb.), Geol. Survey Canada, Mes. Foss., vol. 1, p. 140.
Compare *P. Breweri* Gabb, Palæontology of California, vol. 1, p. 152, pl. 22, fig. 123.

Professor Newberry obtained specimens from Waldron Island, and Mr. Whiteaves reports it as occurring on Sucia Island as well as on

Vancouver Island, but he refers it to *P. royana* d'Orbigny. It is true that this shell is closely like *P. royana* from the Upper Cretaceous of France, but I think it more expedient that the name given it by Mr. Meek should be retained.

In his description of *P. Breweri*, Mr. Gabb seems to have relied mainly upon the difference in the number of radiating ribs shown by his type and Mr. Meek's respectively to distinguish them from each other. The specimens which have been obtained from the Vancouver Island region are so variable as to the number of ribs (a common thing with other species of *Pholadomya*) that I am disposed to regard *P. subelongata* Meek and *P. Breweri* Gabb as one and the same species, as Mr. Whiteaves has done.

ANATINIDÆ.

Genus Anatina Lamarck.

ANATINA SULCATINA Shumard?.

PLATE VI, Fig. 1.

Anatina sulcatina (Shumard) Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 139, pl. 17, figs. 5, 5*a*.

Shell moderately large, subelliptical in marginal outline, inequilateral; posterior end widely gaping; valves broadly convex, abruptly inflexed behind the beaks, but the inflection not reaching the mid-height of the valves; beaks not prominent, situated behind the mid-length of the shell; anterior margin regularly convex; posterior margin somewhat narrowly rounded below, but presenting a slight appearance of oblique truncation above, at the upper end of which it joins the short posterior dorsal margin; anterior dorsal margin somewhat higher than the posterior, gently convex, and rounded down to the anterior margin; surface marked by strong concentric undulations of growth, with a few faint radiating impressions; interior oblique plate well developed.

The largest example in the collections measured, when perfect, about 80^{mm}; height, 50^{mm}.

I am not certain that I ought to refer this shell to the *A. sulcatina* of Shumard, as Mr. Whiteaves has done, and as I here do provisionally. Shumard never figured his species, and I fail to satisfactorily identify it among good collections which I have made from his localities in Texas, but his description agrees so nearly with the characteristics of the shell here described that one can not say positively that it belongs to a different species. Still I think the probabilities are against its being identical with *A. sulcatina* Shumard. Shumard's shell came from the Ripley group of Texas, from which also his *Volutilithes navarroensis* came. This latter shell Mr. Gabb identified in the Chico group of California, and Mr. Whiteaves obtained it from the equivalent of that group upon Sucia Island, where it was associated with the shell here described. On a preceding page I have given my reasons for regarding the shell published by Dr. Shumard under the name of *Volutilithes navarroensis* as distinct from the Pacific coast form with which Mr. Gabb and Mr. Whiteaves have identified it. While the Chico group and its Pacific coast equivalents may have been nearly or quite synchronously deposited with the Ripley group of Texas and other Gulf States, the fauna of the latter is certainly as a whole widely if not wholly different from that of the latter so far as species are concerned.

TEREDINIDÆ.

Genus Teredo Adanson.

TEREDO SUCIENSIS Whiteaves?

Teredo suciensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 135, pl. 17, figs. 1, 1*a*.

Some imperfect specimens in Professor Newberry's collection from Sucia Island are probably identical with the *T. suciensis* of Whiteaves.

GASTEROPODA.

DENTALIIDÆ.

Genus Dentalium Linnæus.

DENTALIUM COOPERI Gabb?

Dentalium Cooperi Gabb, Palæontology of California, vol. 1, p. 139, pl. 21, fig. 100.

Some fragments in the collection from Sucia Island probably belong to this species, but they are too imperfect for satisfactory identification.

RINGICULIDÆ.

Genus Cinulia Gray.

CINULIA OBLIQUA Gabb.

Cinulia obliqua Gabb, Palæontology of California, vol. 1, p. 3, pl. 19, figs. 64–64*c*.
Cinulia obliqua Whiteaves, Geol. Survey Canada, Mes. Foss., vol. 1, p. 131.

The collections from Sucia and Sheep Jack Islands contain many well preserved specimens of this species. Mr. Whiteaves says it is "apparently the most abundant gasteropod of the Nanaimo and Comox coal fields." It is also one of the more common shells in the Chico group of California.

TROCHIDÆ.

Genus Margarita Leach.

MARGARITA ORNATISSIMA Gabb, sp.

Angaria ornatissima Gabb, Palæontology of California, vol. 1, p. 121, pl. 20, fig. 78.
Margarita ornatissima Whiteaves, Geol. Survey Canada, Mes. Foss., vol. 1, p. 128.

A considerable number of specimens occur in the collection from both Sucia and Sheep Jack Islands. They are without doubt identical with the *Angaria ornatissima* of Gabb, from the Chico group of California, but I agree with Mr. Whiteaves in referring the shell to the genus *Margarita.*

SCALARIIDÆ.

Genus Scalaria Lamarck.

SCALARIA MATHEWSONI Gabb.

Scalaria Mathewsoni Gabb, Palæontology of California, vol. 1, p. 212, pl. 32, fig. 27.
Scalaria Mathewsoni Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 128.

The collection from Sheep Jack Island contains a single rather imperfect example, which I have no doubt belongs to this species. Mr. Gabb's type specimens were found in the Chico group of California. Mr. Whiteaves also obtained imperfect examples from Sucia Island.

NATICIDÆ.

Genus Natica Adanson.

Some imperfect specimens, apparently belonging to this genus, were found among the fossils from Sheep Jack Island.

Genus Lunatia Gray.

LUNATIA SHUMARDIANA Gabb.

Lunatia Shumardiana Gabb, Palæontology of California, vol. 1, p. 106, pl. 19, fig. 61.

A single example from Sucia Island apparently belongs to this species.

Genus Gyrodes Conrad.

GYRODES CONRADIANA Gabb.

Lunatia (? *Gyrodes*) *Conradiana* Gabb, Palæontology of California, vol. 1, p. 107, pl. 29, fig. 219.
Gyrodes Conradiana Gabb., Palæontology of California, vol. 2, p. 222.
Compare with *Gyrodes excavata* Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 124, pl. 16, figs. 2, 2*a*.

Several imperfect examples occur among the collections from both Sucia and Sheep Jack Islands, which appear to be young examples of this species. I am also of the opinion that they belong to the same species which Mr. Whiteaves (op. cit.) referred to the *Natica excavata* of *Michelin* as published in Paléontologie française.

NERITOPSIDÆ.

Genus Vanikoropsis Meek.

VANIKOROPSIS SUCIENSIS, sp. nov.

PLATE VII, Fig. 4.

Shell small, subovoid, spire small; its apex blunt; volutions four or five in number, convex; the last one much expanded and constituting the greater part of the bulk of the shell; aperture large, oval; entire surface marked by numerous raised revolving lines.

Only a single example was found, but, as it seems to represent a well-marked species, a description and figures of it are given. It occurs among the fossils from Sucia Island.

The length of this example is 8^{mm}, and the greatest breadth across the last volution is about the same.

FASCIOLARIIDÆ.

Genus Fusus Lamarck.

FUSUS KINGI Gabb.

Fusus Kingi Gabb, Palæontology of California, vol. 1, p. 85, pl. 28, fig. 204.

Fusus Kingi Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 119, pl. 15, fig. 4.

A single imperfect specimen was found on Sheep Jack Island. Mr. Whiteaves obtained it on Sucia Island also.

Genus Perissolax Gabb.

PERISSOLAX BREVIROSTRIS Gabb.

A fragment of this species occurs among the fossils collected on Sheep Jack Island. Mr. Whiteaves also obtained it from Sucia Island.

VOLUTIDÆ.

Genus Fulguraria Schumacher.

FULGURARIA GABBI White.

Volutilithes navarroensis Gabb (not Shumard), Palæontology of California, vol. 1, p. 102, pl. 19, fig. 56.

Fulguraria navarroensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 117, pl. 15, figs. 3-3*a*.

Fulguraria Gabbi White, this bulletin, p. 23, pl. 3, fig. 1.

Specimens of this species were found on Sucia and Sheep Jack Islands; and Mr. Whiteaves obtained it also from Vancouver Island.

The supposed relation of this form to the *Volutilithes navarroensis* of Shumard is discussed on page 24 of this bulletin.

CEPHALOPODA.

BACULITIDÆ.

Genus Baculites Lamarck.

BACULITES CHICOENSIS Trask.

Baculites chicoensis Trask, Proc. Acad. Nat. Sci. San Francisco, p. 85, pl. 2, fig. 2.
Baculites chicoensis Gabb, Palæontology of California, vol. 1, p. 80, pl. 14, figs. 27, 29, 29*a*.
Baculites chicoensis Meek, Bull. U. S. Geol. Survey Terr., vol. 2, p. 364, pl. 4, figs. 2–2*c*.
Baculites chicoensis Whiteaves, Geol. Survey Canada, Mesozoic Fossils, vol. 1, p. 114.

The *Baculites* found in the Chico group of California, and to which Dr. Trask gave the name of *B. chicoensis*, is not an uncommon form in the Vancouver group, among the collections from which it has been recognized by Meek, Gabb, and Whiteaves. Professor Newberry's collections from Sucia and Sheep Jack Islands contain a considerable number of examples of *Baculites*, a part of which at least are clearly referable to *B. chicoensis*. Some of the specimens are much larger than any which I know to have been found in the Chico group of California; and they so greatly resemble *B. ovatus* Say, that one can hardly say how they differ from the typical forms of that well-known species. Among these specimens, however, are others of intermediate size which seem to connect all these forms together as one species, for none of them present differences of structure that can be reasonably regarded as of specific value.

Among these specimens are some also which show a slight flattening upon the dorsal side, upon which character Mr. Meek relied to distinguish his *B. occidentalis*, which he found associated with *B. chicoensis* in the Vancouver group. I do not, however, regard these specimens as specifically distinct from the others of the collection, and I have much doubt whether there is more than one species of *Baculites* in the Vancouver group. The dorsal flattening of *B. occidentalis* it is believed may be only a varietal character; and it seems quite probable that the difference in size between the large specimens from the Vancouver group and ordinary forms of *B. chicoensis* may also be only varietal. The constantly small size of *B. chicoensis* in the Chico group of California is perhaps due to environing conditions at the time the mollusks lived.

AMMONITIDÆ.

Genus Ammonites Bruguiere.

AMMONITES NEWBERRYANUS, Meek.

Ammonites Newberryanus Meek. Trans. Albany Inst., vol. 4, p. 47.

Ammonites Newberryanus Gabb. Palæontology of California, vol. 1, p. 61, pl. 10, figs. [illegible] pl. [illegible] fig. [illegible].

Ammonites Newberryanus Meek. Bull. U. S. Geol. Survey Terr., vol. 2, p. 367, pl. 4, fig. [illegible]

Ammonites Newberryanus Whiteaves. Geol. Survey Canada. Mesozoic Fossils, vol. 1, p. 60, pl. 14, figs. 1, 1a.

The collections contain specimens of this species from Sucia Island; and the authors cited have obtained it from Vancouver and other islands in that region. Characteristic specimens of the species have also been obtained at several localities of the Chico group in California. While not an abundant fossil in the latter strata, it may be regarded as a characteristic species of both the Chico and Vancouver groups.

This species is subject to much variation as regards its surface features. In some cases every fourth or fifth rib upon the earlier volutions is sharply raised above the others. In other specimens neither of these features appear, but the ribs and spaces are more or less uniform. These differences are sometimes so striking, that Mr. Meek (vide op. cit.) was in doubt whether the form published by Gabb really belongs to this species.

AMMONITES MACLUREI, sp. nov.

PLATE VII, Figs. 2, 3.

Volutions slender, slightly embracing, regularly rounded upon the periphery, a little less convex at the sides, and somewhat abruptly rounded into the umbilicus, near which is the greatest diameter of the volutions; umbilicus moderately broad, showing all the inner volutions; septa complex, but their details are not fully known. The whole surface is plain, and in a partially exfoliated condition it is quite smooth, but where a part of the external surface of the shell is preserved, slightly raised revolving striæ appear. They are crossed by fine striæ of growth and occasional constrictions, which show that the outer portion of the margin of the aperture projected much forward, and that it had a broad emargination at the peripheral side.

This shell bears considerable resemblance to *A. Batesi* Gabb, from the Shasta group of California; but it differs from that species in having a much narrower umbilicus, an emargination of the peripheral border of the aperture, less distinct marks and undulations of growth, and the presence of longitudinal striæ upon the whole surface. Only a single imperfect specimen of this form is known; but it is so different from any other member of either the Chico or the Vancouver fauna with which I am acquainted, that it is thought best to give it a name. It was discovered on the Sucia Island by Mr. E. W. McClure, who collected a a large part of the fossils sent by Professor Newberry.

PART IV.

THE MOLLUSCAN FAUNA OF PUGET GROUP.

GENERAL REMARKS ON THE GEOLOGY OF THE GROUP.

Besides the collection of Cretaceous fossils from the Vancouver group which form the basis of the preceding article of this bulletin, Professor Newberry has placed in my hands a collection of brackish-water fossil mollusca from the Puget Sound region, which represent a hitherto unpublished fauna. The formation from which they were obtained is known to occupy a large part of the Puget Sound basin, extending also along its eastern side, the western flank of the Cascade Range. Besides these strata which lie to the west of that range other similar deposits are found upon its eastern flank, as well as among its higher mountains. These strata are also coal-bearing, and are believed to belong to the same formation, although they have not yet furnished any molluscan fossils similar to those found upon the western side of the Cascade Range. The unique character of this molluscan fauna shows that the series of strata in which their remains are found were deposited in a separate body of water from that of any other known coal-bearing strata in the Pacific Coast region or elsewhere; and its zoölogical character indicates that that body of water was an estuary.

The most complete information which has yet been published concerning this formation has lately appeared in volume 15 of the reports of the Tenth U. S. Census, pages 759–771, Plates LXXXII–CII. That publication, which is entitled a "Report on the coal-fields of Washington Territory," is by Mr. Bailey Willis, who accomplished the work upon which his report is based under the auspices of the Northern Transcontinental Survey. The special object of his report being a presentation of the coal resources of that region, the discussions are confined mainly to the coal-bearing formations, and it therefore does not embrace a full account of the structural geology of the whole region. Still, Mr. Willis has given some very comprehensive facts as well as many elaborate details of this coal-bearing series of strata in the report referred to; and as my own field labors upon the Pacific coast have never extended north of the Columbia River, much that is embraced in the following remarks, besides the quoted paragraphs, is based upon information personally imparted by him.

The land elevations of the Pacific Coast region extend in two lines, which are approximately parallel with each other and with the coast. The eastern one consists of the Sierra Nevada in California, and of the Cascade Range in Oregon and Washington Territory. The western one, known as the Coast Range in California, extends with some interruptions through Oregon and thence northward of the Columbia River, but it there sinks to low hills before reaching the Olympic cluster of mountains, which constitute the northern end of the line, and whose higher peaks rise to more than 8,000 feet above the sea.

These mountain reliefs of the Pacific Coast region are the product of several uplifts, differing in time, extent, and locality in the different ranges and different parts of the same range. A full history of these movements has not yet been learned, but the following may be regarded as facts which are of interest in this connection.

The Cascade Range, which has been recognized as distinct from the Sierra Nevada Range, although in general line continuous with it, and which has been considered to be itself simple, is in reality quite complex. In Oregon it is composed of erupted material, which has there been observed to rest upon nearly horizontal sedimentary strata of Cretaceous age; and in southern Washington Territory it consists of enormous masses of eruptive rocks, overlying highly flexed sedimentary strata of late Mesozoic or early Tertiary age. In the northern half of the same Territory the range is made up entirely of granite, crystalline schists, and volcanic rocks. The Tertiary rocks, which prevail in the Coast Range generally, seem to be wanting in the Olympics, which in this respect, and in their composition, resemble the northern portion of the Cascade Range.

Between the two long orographic lines before referred to lie the great broad valleys of the Sacramento and San Joaquin Rivers of California, of the Willamette in Oregon, and of Puget Sound (known as the Puget Sound basin) in Washington Territory. The latter was the scene of deposition of at least the greater part of the coal-bearing series which is characterized by the molluscan fauna described in this article. This fauna has been discovered only within the present limits of Puget Sound basin; but if the strata before referred to, which are found upon the eastern side, as well as in the body of the Cascade Range of southern Washington Territory, constitute parts of the same formation, the scene of its deposition extended much beyond the present limits of Puget Sound basin. This conclusion of course implies that that portion of the Cascade Range upon which those strata are found was not then elevated, as was the northern portion, and that the outline of the area within which this series of strata was deposited was very different from what would be suggested by the present topographical features of that region.

That the present topographical features of the region differ greatly from those which prevailed during the Puget epoch is indicated by others of Mr. Willis's observations. Among these he noticed the absence of strata of the Puget group up high in both the Olympic and the Northern Cascade Mountains; which, in connection with the present known areas occupied by strata of that group, leads him to believe that while those strata were being deposited, the Olympic Mountains constituted an island, and the Northern Cascades a peninsula.

The following remarks concerning the floral relations of these Puget Sound strata with other better-known formations have been furnished by Professor Newberry:

> The plant-bearing strata of the region about Puget Sound represents several distinct horizons. The collections from different localities show great differences, sometimes having nothing in common, and further collections will be needed before the different floras can be satisfactorily co-ordinated. It is plain, however, that leaving out of view the coal bearing strata of Queen Charlotte's Island, which are evidently Lower Cretaceous and probably the equivalent of the Kootanie group of Dawson, most of the beds from which I have fossil plants are in a general way about of the age of the Laramie, and apparently bridge over the interval between the Cretaceous and Tertiary.
>
> I have found in my collections from the Puget Sound region a few species which are identical with some obtained from the Laramie on the east side of the mountains. For example, my *Sphenopteris* (*Asplenium*) *elongata*[1] occurs at Orcas Island, Chuckernuts, and at Carbonado, and this is identical with Lesquereux's *Gymnogramma Haydeni*,[2] and also identical with Saporta's *Asplenium subcretaceum*,[3] and Gardner's *Anemia subcretacea*.[4] This is a wide-spread species, and doubtless has a great vertical range, being both Upper Cretaceous and Eocene.
>
> Again the most common plant found at Carbonado and Flett's Creek is a palm, which I can not distinguish from Lesquereux's *Calamopsis Danæ* from the Lignitic of Mississippi. With these, however, are large numbers of species which are not found east of the mountains or elsewhere. You will remember that the very large bivalves which you have studied and named [*Batissa Newberryi*] came mostly from Carbonado and Flett's Creek, but the same species occurs in Newcastle, where the plants are all different.
>
> From Whatcom Lake I have specimens of *Onoclea sensibilis*, which occurs in such abundance at Fort Union but with many other associated plants there is no other Laramie species. I think we shall ultimately find that all the local floras of the Puget Sound series are united by a few common species, and that some of these occur in the Upper Cretaceous beds of Greenland and in the floras of Sézanne and Gelinden. Nearly all the species are new, but it is easy to see that the flora taken as a whole is most like that of the Upper Cretaceous and Lower Eocene of the Old World.
>
> So far I have found nothing common to the Puget Sound flora and distinctly Tertiary floras of the Green River, the Current Creek, and John Day beds, unless it is a *Lygodium*, that occurs at Flett's Creek, and which can hardly be distinguished from Lesquereux's *L. neuropteroides*, so common in the Green River group. But according to Gardiner this is identical with *Lygodium Kaulfussi*, Heer, and is cosmopolitan in its distribution, and therefore has great vertical range.

For the purpose of presenting the best statement of the general geology of the Puget Sound region which is at present available, the following quotations are made from Mr. Willis's published report before referred to, pages 759-761:

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[1] Boston Jour. Nat. Hist., vol. 7, p. 511.

[2] U. S. Geol. Survey Terr. vol. 6, p. 59, pl. 5, figs. 1-3.

[3] Flor. Foss. Sézanne, 1868.

[4] Palæontographical Society, 1880, p. 45.

> The Coal Measures of the Puget Sound basin consist of alternating beds of yellow and gray fine-grained sandstones and very fine gray arenaceous shales, interstratified with many beds of carbonaceous shale and coal; the individual strata of sandstone and shale from twenty to two hundred feet thick maintain the same general character wherever observed, and no well-defined horizon has been found which might serve as an index to correlate the widely separated exposures. Leaf impressions occur in both shales and sandstones associated with Unios.[1]
>
> Collections made by the Northern Transcontinental Survey have been submitted to Prof. J. S. Newberry, who considers them the equivalent of the Laramie east of the Rocky Mountains, and of greater antiquity than the Tertiaries of Bridge Creek and John Day's Valley in eastern Oregon. These collections relate, however, principally to the lower measures of the Wilkeson field of bituminous coal, and it remains to be seen whether further evidence, now being gathered, will sustain the inference, drawn from stratigraphical relations, that the lignites and bituminous coals belong to one age.
>
> The thickness of the Laramie group, as determined by Mr. George H. Eldridge, in Montana, is about 8,500 feet in the Bull Mountains, and very much less near the old shore-lines. On the Pacific coast it greatly exceeds the above maximum; but it is not possible without further study to state even an approximate total, on account of the uncertain relations of the much-disturbed strata, obscured by volcanic flows, recent drift, and a dense forest.
>
> The best sections are those obtained in the Wilkeson and Green River fields. * * * Of these, one gives a minimum of 13,200 feet, with a probable maximum of 14,500 feet; a second, still less complete, measures 7,700 feet; and the third, on Green River, lies between 6,200 and 8,200 feet; and these sections do not in either case reach the limits of the Coal Measures, as the base of each is an anticlinal axis and the top the highest exposure, geologically speaking, beneath the volcanic flows or drift beds. Such figures challenge confirmation,[2] but they are the result of accurate surveys and careful observation, and are only invalidated by the possibility of undiscovered faults, of which the sections have yielded no proof under close examination.
>
> The fossils indicate the maintenance of fresh and brackish water conditions through this long period of deposition, implying that the general rate of this profound subsidence was the same as that of accumulation of sediments.
>
> The circumstances of deposition were subject to frequent and probably often local changes; the preponderance of layers of fine sandstone, apparently derived from granite, suggests clear currents and pools existing contemporaneously with shallow waters and marshes, in which muddy sediment and peat accumulated; and the succession of sandstones, shales, and coal veins in the column of strata indicate as many changes of depth and current over the same locality. In the first of the above-mentioned sections there are one hundred and twenty-seven Carbonaceous beds, of which seventeen are workable coal veins three to fifteen feet thick.
>
> Outcrops of older rocks in the vicinity of these Coal Measures are usually of granite or crystalline schists, either serpentine or chloritic; in the San Juan archipelago there are evidences of Cretaceous strata, and a hint of their existence is found in some indistinct agatized casts of oval cross-section and about two inches long, which were brought from a conglomerate on the upper Skookumchuck southeast of Tenino; they were unfortunately lost, but were apparently casts of *Baculites*. These would

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[1] These shells have much the outward aspect of *Unio*, but, as is shown on a following page and illustrated on Plate IX of this bulletin, they have the hinge characters of *Batissa*.—C. A. W.

[2] Mr. Willis has informed me since the above was written that subsequent information has led him to doubt whether these estimates of thickness are not somewhat too great.—*C. A. W.*

seem to be the edges of a Cretaceous deposit hidden beneath the more extensive later rocks. But one contact of the Coal Measures with underlying schists has been observed, and that is of uncertain character. * * *

The region over which this deposition occurred has since been the scene of mountain-making upheaval, of stupendous volcanic eruptions and enormous erosion, both glacial and subaërial. The definition of its boundaries and extent is a correspondingly difficult, perhaps in some directions impossible, task.

Looking at the Puget Sound basin as a whole, the Coal Measures extend from beyond the British boundary south almost to the Columbia, and from the Pacific Ocean eastward up onto the Cascade Range to elevations varying from 800 to 5,000 feet above the sea; but buried on the one hand beneath recent gravel-beds, and overflowed on the other by erupted masses, the visible part of the formation appears as an interrupted belt along the base of the Cascades and encircling the Olympic Mountains.

The geological section of the Puget Sound basin as developed in the exploration of these coal fields may be provisionally stated as follows:

(1) Present surface of humus, accumulating from beds of *Hypnum splendens*, and the contributions of ferns, shrubs, and evergreens of the damp, luxuriant forests, average thickness probably four inches, though frequently wanting where fires have occurred within two centuries.

(2) Beds of coarse and fine gravel, sand, and clay, intimately mingled and distributed by swift currents; composed almost wholly of hard volcanic material, highly polished and sometimes striated. These drift beds fill the deeply eroded valleys of all the rivers entering the sound to an unknown depth; they form well-defined terraces[1] at Wilkeson 1,600 feet above the sea, with a known thickness above the solid rock of 300 feet, and occur in terraces[1] at an elevation of 2,000 feet on the western slope from the Natchez pass.

(3) Tertiary volcanic rocks, which form the highest peaks of the Cascade Range (Mount Rainer, 14,300 feet), and detached mountain masses and ridges. They occur as intrusive dikes in the Coal Measures, often with an appearance of conformability and as flows, beneath which the coal-rocks disappear.

(4) The lignitic and bituminous Coal Measures, sandstones, and shales probably exceeding 13,000 (?) feet in thickness; Laramie ?.

(5) Cretaceous strata of the San Juan Islands and conglomerate ? of the Skookumchuck.

(6) Serpentine or chloritic schists, associated with limestones and marble beds, containing segregated auriferous quartz veins, and on the Skagit silicious specular iron ore. These highly metamorphosed strata form, with granite, the mass of the Cascade Range, and are similar in association to the same rocks in northern Washington Territory and those of western Idaho; they are pre-Cretaceous and possibly Paleozoic.

Granite covers a large area west of the crystalline schists of the Skagit, reaching beyond Lake Chelan to the Okinakane and eastward to the Colville region, though sometimes hidden beneath more recent material.

Turning to the eastern slopes of the Cascades, there appears a small development of Coal Measures similar to those of the Puget Sound basin near the head of the Yakima River and on the Wenatchie River. They crop out near Lake Kitchelas, Lake Klealim, and on Schwak Creek, a small tributary of the Yakima from the north; they are of limited extent, and probably not more than 1,000 feet thick. They rest conformably (?) upon 7,000 or 8,000 feet of coarse sandstone containing thin layers of conglomerate, at the base of which is a bed of coarse conglomerate 300 to 400 feet thick. The best exposures of these rocks are south of the Wenatchie, on the spur of the Cascades called the Peshasten Range, which divides that river from the Yakima. The same sandstone and conglomerate beds occur at the head of the Munastash Creek, 25 miles west of Ellensburgh, at an elevation of 5,500 feet, on the main Cascade Range.

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[1] Probably morainal terraces.—B. W.

The probability that these strata east of the range correspond to the Coal Measures west of it is suggested in the following:

Comparison of sections.

West of the Cascades.	East of the Cascades.
(1) Wide-spread glacial drift.	(1) Limited glacial drift. Lake beds of the Yakima and Columbia Rivers.
(2) Tertiary volcanic rocks.	(2) Tertiary volcanic rocks.
(3) Lignitic and bituminous Coal Measures, characterized by angiospermous leaf impressions throughout the entire thickness, thirteen thousand feet or more.	(3) Coal Measures of limited extent, one thousand feet. Coarse sandstone, with thin conglomerate beds, seven thousand to eight thousand feet.
(4) Cretaceous strata and conglomerate of the Skookumchuck.	(4) Conglomerate, three hundred to four hundred feet thick.
(5) Serpentinic or chloritic schists, associated with limestone and resting on granite, common to both sides of the range.	

The extent of the Cretaceous strata requires further study, but the existence of Laramie (?) sandstones upturned high upon the mountains places their upheaval at the close of that period.

Mr. Willis has also kindly furnished me with the following paragraph from an unpublished report of his, upon a district which lies eastward of Puget Sound basin:

> ### LARAMIE (?) OF THE WENATCHIE VALLEY.
>
> The Wenatchie River cuts a section across unmetamorphosed conglomerates and sandstones, bent in broad folds over axes having a general north and south trend. This formation flanks the Peshastan Range on both sides, occurring on the south on Schwak Creek and in the Klealim Valley, and forms some of the high crests of the Cascade Range north of the Natchez. It is the last formation deposited before the elevation of the Cascade Range and its spur, the Peshastan, and is thus identified, as well as lithologically and in its stratigraphic relations, with the Puget Sound Coal Measures, the latter having been assigned to the Laramie on the evidence of the leaf impressions by Prof. J. S. Newberry.

In the last-quoted paragraph Mr. Willis shows his reason for identifying those strata which are found within and upon both the eastern and western sides of the Cascade Range as belonging to one and the same formation. It will be seen also that, in consequence of the identification by Professor Newberry of certain Laramie species of plants and of the probable superposition of the Puget group, at least in part, upon Upper Cretaceous marine strata, he regards the Puget group as geologically equivalent with the great Laramie group, which latter name he has also provisionally applied to it. I think all the known evidence is strongly in favor of this view, which is taken by both Professor Newberry and Mr. Willis, but the character of their respective molluscan faunas makes it quite certain that the deposition of these two formations took place in different bodies of water, which, if contemporaneous, were completely separated by a land area. That area was necessarily of considerable width, but yet an arboreal flora may be reasonably supposed to have occupied its whole breadth, and to have scattered its autumnal leaves into the Laramie sea upon the one hand and into the Puget estuary on the other, while the aqueous faunas were respectively very different. It may yet appear that land vertebrate and molluscan faunas also extended across the same area, and that remains of each found their way into the Laramie sea upon the one hand and the Puget estuary on the other.

While the evidence which is furnished by the fossil mollusca of the Laramie and Puget groups, respectively, is conclusive that they were deposited in separate bodies of water, satisfactory evidence exists also that the Laramie outlet was into Atlantic and the Puget outlet into Pacific waters. When such differences of conditions as these are known to have prevailed, resulting in or connected with marked faunal dissimilarities, I think it much better to use separate names for the formations, even if correlated evidence should be satisfactory that they were contemporaneous in their origin. It seems at least expedient also that separate local names should be applied to certain marine strata which are found in separate districts, but shown by a greater or less proportion of the species of fossils they respectively contain to have been at least approximately contemporaneous. In accordance with this view I have proposed the name "Puget group" for the deposit which forms the subject of this article, as I did that of "Vancouver group" for the formation under discussion in Part III of this bulletin.

As to the original boundaries of the Puget group comparatively little is definitely known. It is probable also that much will remain unknown upon this point, owing to the great erosion and disturbance which the strata have suffered and to the presence of large portions of the immense lava outflows which have so largely covered them. Taking into consideration the extreme points at which strata of this group have been found, including those which lie to the east of and among the Cascade Mountains, it is evident that the Puget deposit originally occupied an area of several thousand square miles. Still any definite estimate must be unsatisfactory, owing to the evidently great irregularity of the original as well as the present area.

That the body of water in which the Puget group was deposited was estuarine, and not a land-locked sea, as was the Laramie, is indicated by its molluscan fauna, all the known members of which are described and figured in this bulletin.[1] But in what manner the Puget estuary was separated from the open sea we have as yet little information. A natural inference would be that the Olympic Island formed a part of such a barrier, but the presence of marine fossils in the valley of

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[1] The apparent absence of this peculiar fauna from the more eastern strata suggests that they were deposited nearer to the influx of fluviatile waters, which, being there entirely fresh and farther inland, did not afford a congenial habitat for species which prevailed in the western and brackish part of the estuary.

Dwamish River, the strata inclosing which were presumably deposited contemporaneously with at least a portion of the Puget group, would seem to show that the estuary barrier was, a part of the time at least, eastward of Olympic Island.

Besides the information contained in those of the foregoing paragraphs which are quoted from Mr. Willis's report, little is known concerning the stratigraphical relations of the Puget group to the other formations of the Pacific Coast region. Its molluscan fauna, being unique in character and composed of types which give little or no definite indication as to geological age, is comparatively worthless as an aid in correlating the Puget group with any other formation.

Mention has just been made of the presence of marine fossils in certain strata on Dwamish River, in Puget Sound basin. This locality and its fossils have been briefly discussed in Part II of this bulletin, where it is shown that the greater part of the species found there are identical with species found in the Téjon group of California. The locality is just westward of, and not distant from, a district which is occupied by the characteristic strata of the Puget group, which furnished the fossils described and figured on following pages. Mr. Willis, who has studied the stratigraphy there in connection with his work before referred to, regards the position of these marine strata with reference to those of the Puget group as having been deposited not earlier than those of the upper portion of that group. This view of the stratigraphical relations of the Dwamish River strata with those of the Puget group, together with the fact that their fossils are of marine origin, suggests that they were deposited in marine waters towards the close of the great subsidence that accompanied the deposition of the Puget group, and indicates that the latter group is a local, although a large, representative of a part, or the whole, of the Chico-Téjon series. It also seems to indicate that the western barrier of the Puget estuary was at that time and place not far from the middle of the present Puget Sound basin; but it is probable that the position of the barrier was shifted from time to time during the existence of the estuary.

It is in consideration of the following facts that the Puget fauna has been designated as of estuary origin: No trace of a characteristic open-sea fauna has been found in the Puget strata. The genera *Corbicula* and *Batissa*, which are known to range from brackish to fresh waters, but not into marine waters, constitute a conspicuous portion of that fauna. These are associated with certain forms whose living congeners are known to range from marine to brackish waters, but not into fresh waters. The strata contain an abundance of vegetable remains, which doubtless came from swamps and adjacent shores.

Now, if the strata of the Puget group were deposited, even in part contemporaneously with the Chico-Téjon series, it is probable that some of the molluscan species of that series which were capable of entering brackish waters may yet be found in the Puget strata, and that some of the species of the Puget fauna which were [illegible] waters are yet to be found associated with Chico-Tejon species. As a matter of fact, however, no evidence of such a commingling of the species of the two faunas has yet been discovered. [illegible], therefore, we have no paleontological evidence of the contemporaneity of the Puget group with the Chico-Tejon series.

Although it seems quite evident that the Puget group was deposited in estuarine waters, there are certain facts which are somewhat perplexing when considered in connection with an acceptance of that view. The known area within which strata of that group occur shows that the Puget estuary was of such great extent that it is difficult to understand how so large a body of water could have been sufficiently kept so nearly fresh as to afford a congenial habitat for such a molluscan fauna as it is known to have possessed, and during so long a period of time as was necessary for the accumulation of the great thickness of strata in which the remains of that fauna are found. That is, it is difficult to understand how that comparatively narrow portion of the continent between the then existing Laramie hydrographic basin on the east and the Puget estuary on the west could have furnished a sufficient flow of fluviatile waters to keep nearly fresh so large an estuary, and keep off the encroachment of adjacent marine waters. Even so large a flow as is now discharged by the Columbia River would seem to have been insufficient, unless the outlet of the great estuary was much restricted by land barriers.

Again, the evidence presented by Mr. Willis, and also that afforded by the fossils, which range without material change through a large part of the vertical series, seems to be conclusive that essentially uniform estuarine conditions were preserved over the whole area now occupied by the Puget group from the time of the deposition of its earliest to that of its latest strata. This evidence also discloses the remarkable fact that during that time there was a constant subsidence over the whole area until it had reached a maximum of twelve thousand feet or more. It is certainly difficult to see how so great a subsidence could have taken place without such a simultaneous elevation of the adjacent land area as would have materially changed the character and uniformity of the supply of fluviatile waters to the estuary, or have added a land area to the westward of it. Indeed, it is difficult to understand how even a less subsidence could have taken place without materially modifying the character of the great estuary itself, or even submerging its whole area beneath marine waters.[1]

The localities from which were obtained the molluscan fossils of the Puget group, and which are described in the pages immediately following, lie mainly in King and Pierce Counties, Washington Territory. These localities are designated upon the labels accompanying the fossils as Newcastle, Wilkeson (Flett's Creek), Carbonado, Green River, and

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[1] See second foot-note on page 481.

Palace Camp, respectively; and these names occur in connection with the descriptions.

The following is a list of the species recognized in Professor Newberry's collection and herein described:

Cardium (Adacna?) ——— ?
Cyrena brevidens.
Corbicula Willisi.
Corbicula pugetensis.
Batissa Newberryi.
Batissa dubia.
Psammobia obscura.
Sanguinolaria ? caudata.
Teredo pugetensis.
Neritina ——— ?
Cerithium ? ——— ?
Undetermined gasteropod.

DESCRIPTION OF SPECIES.

CONCHIFERA.

CARDIIDÆ.

Genus Cardium Linnæus.

CARDIUM (ADACNA ?) ——— ?

PLATE IX, Fig. 4.

The collection from the locality designated as Palace Camp contains a couple of imperfect examples of a shell which plainly belongs to the Cardiidæ. The general form and the character of the hinge and of the pallial impression, together with its brackish-water associates, suggest the propriety of referring this shell to the genus *Adacna*; but the material in hand is too imperfect to make that reference with confidence.

The shell is subelliptical in marginal outline; wider than high; and the surface is marked by numerous sharply raised radiating ribs; cardinal teeth small; lateral teeth moderately well developed; pallial sinus apparently large and deep.

Breadth, 24^{mm}; height about 16^{mm}.

The specimens are in the condition of casts only, and being also fragmentary, a full specific description is impracticable.

CYRENIDÆ.

Genus Cyrena Lamarck.

CYRENA BREVIDENS, sp. nov

PLATE X, Figs. 8–11.

Shell subtrihedral in outline by lateral view; valves moderately convex; beaks prominent, situated a little in advance of the mid-length *of the shell even* in the shortest examples; cardinal teeth small; posterior lateral teeth small and slender; anterior lateral tooth of the left valve very short, and situated so near to the cardinal teeth as to appear like an accessory cardinal tooth; pallial sinus small and moderately deep. Surface marked by distinct concentric lines and undulations of growth.

The proportion of height to the length of the shell varies greatly in different examples. One example measures 27^{mm} in height and 33^{mm} in extreme length, while another measures 18^{mm} in height and 26^{mm} in extreme length. The average proportions are, however, between those of these two examples.

In outward aspect this shell resembles *Corbula*, but the character of the hinge is quite unlike that of *Corbula*, and the valves are also equal in shape and convexity. In the character of the lateral teeth it also differs considerably from the typical forms of *Cyrena*. The posterior laterals are of much less than ordinary size, while the anterior lateral tooth of the left valve is so close to the cardinal teeth as to serve and appear as an additional cardinal tooth. This difference in the hinge is probably of subgeneric value, but for the present I prefer to place the shell under *Cyrena*.

Locality.—Palace Camp.

Genus Corbicula Megerle.

CORBICULA WILLISI, sp. nov.

PLATE XI, Figs. 3-7.

Shell subcircular in outline, the height and length being nearly equal; beaks prominent, elevated, and situated near or a little behind the mid-length of the shell; valves strongly convex, especially in the umbonal region; front margin regularly rounded, its convexity being continuous with the somewhat less convex basal margin; posterior margin slightly convex, nearly perpendicular, and abruptly rounded to the basal margin below and to the dorsal margin above; dorsal margin short, nearly straight; cardinal teeth well developed; lateral teeth also well developed and transversely crenulated; pallial sinus small. The surface is marked by the ordinary concentric lines of growth, and the larger examples usually have besides this a greater or less number of strong concentric undulations.

Height of the largest example in the collection, 54^{mm}; length, 51^{mm}; but the average size is considerably less.

This is a typical American fossil form of *Corbicula*, having the crenulated lateral teeth and small pallial sinus which characterize those forms. In shape and general character it approaches the *C. umbonella* of Meek, from the Laramie group; but it is shortened more abruptly behind, and the front is more prominent.

Localities.—Carbonado, Wilkeson (Flett's Creek), and valley of Green River.

CORBICULA PUGETENSIS, sp. nov.

PLATE XI, Fig. 8.

Associated with the foregoing species at Carbonado is a form which differs so much from it as to warrant the application of a separate name. It is subovoid in marginal outline, considerably longer than high; valves moderately convex; beaks somewhat prominent, situated near the anterior end of the shell; surface marked by the ordinary concentric lines of growth.

Height of an example of ordinary size, 35^{mm}; length, 45^{mm}.

This species is readily distinguishable from the foregoing one, with which it is associated, by its more elongate form, the anterior position of the beaks, and the prominent posterior border. In general aspect it somewhat closely resembles *Corbicula* (*Leptesthes*) *cardiniæformis* White, from the Laramie group; but the front of this shell is even less prominent than that of the Laramie species.

Genus Batissa Gray.

BATISSA NEWBERRYI, sp. nov.

PLATE IX, Figs. 1-3.

Shell large, subelliptical in marginal outline; valves moderately convex; beaks slightly prominent, situated behind the mid-length of the shell; cardinal margin broadly arched; front margin somewhat abruptly rounded; basal margin broadly convex, and the posterior margin a little more narrowly rounded than the front; ligament large, prominent, and ending abruptly behind, as is usual in this genus; cardinal teeth three in each valve, the two posterior ones of the right valve being broad and strong, and all three teeth of the left valve being narrow; lateral teeth unknown.

Height of the most perfectly preserved example in the collection, 52^{mm}; length, 81^{mm}; but the average size is considerably larger than this.

The collection contains numerous examples of this species, all of which are more or less distorted by the pressure to which the material they were embedded in has been subjected. In some cases the distortion has been so extreme as to have wholly destroyed the original form of the shell. In all cases also the shell substance has been dissolved away, but most of the examples show the beaks to have been much corroded while the mollusk was yet alive, as those of living species of *Batissa* often are. This total destruction of the shell substance of these specimens of *Batissa* in the process of fossilization is noteworthy, because nearly all of the specimens of *Corbiculla* and *Cyrena* which are found associated with them, and which belong to the same family, have the shell substance preserved.

Localities.—*Carbonado,* Wilkeson (Flett's Creek), and Newcastle.

BATISSA DUBIA, sp. nov.

PLATE XI, Figs. 1, 2.

Among the collections from Newcastle and Wilkeson are numerous compressed and distorted examples of a shell which I refer to the genus *Batissa*, but which is evidently specifically different from *B. Newberryi*. It is a smaller shell, subcircular in marginal outline, and has its beak situated a little in advance of the mid-length of the shell. The ligament is large and prominent, and one of the examples shows traces of the cardinal teeth similar in character to those of *B. Newberryi*.

TELLINIDÆ.

Genus Psammobia Lamarck.

PSAMMOBIA OBSCURA, sp. nov.

PLATE X, Figs. 4-6.

Shell irregularly subelliptical in marginal outline; valves gently convex, but the postero-dorsal region is somewhat compressed; beaks not prominent, situated at about one-third the full length of the shell from the front; anterior margin rounded; basal margin broadly convex; dorsal margin behind the beaks nearly straight; postero-dorsal margin sloping downward and backward to the base. Surface marked by the usual distinct concentric lines of growth. Pallial line strong, and its sinus large and deep.

Height, 29^{mm}; length, 38^{mm}.

Localities.—Palace Camp and Carbonado.

Genus Sanguinolaria Lamarck.

SANGUINOLARIA? CAUDATA, sp. nov.

PLATE X, Figs. 1-3.

Among the collections made at Carbonado are some imperfect examples of a somewhat extraordinary shell, which I refer provisionally to *Sanguinolaria*. Up to the time of its reaching nearly adult size its general shape and marginal outline agree with the recognized forms of *Sanguinolaria;* but from that time until fully grown the posterior portion became so greatly extended, that extreme examples reach nearly double the length which the shell had before the posterior elongation began.

No trace of the hinge has been discovered, and the specimens found are so imperfect, that no satisfactory specific description can be given. The figures, however, on Plate X will serve to give a good idea of all that has been learned of this singular shell.

TEREDINIDÆ.

Genus Teredo Adanson.

TEREDO PUGETENSIS, sp. nov.

PLATE VIII.

The shell of this species is not known, the specimens in the collection consisting only of the tubes, solidly filled with stony material in a mass of partially carbonized and partially silicified wood. The tubes are large, most of them extending in the direction of the wood fiber, and terminate at the distal end in almost true hemispheric convexity.

The diameter of the tubes, as seen in the specimens in hand, varies from 27^{mm} to 32^{mm}.

Locality.—Carbonado.

GASTEROPODA.

NERITIDÆ.

Genus Neritina Lamarck.

NERITINA ——— ?

PLATE X, Fig. 12.

Among the specimens collected at Palace Camp is a single example of *Neritina*, which is in the condition of a natural cast of the interior of the shell. It is too imperfect for specific description, but its character is partially shown by the figure on Plate X.

CERITHIIDÆ.

Genus Cerithium Bruguière.

CERITHIUM ? ——— ?

PLATE IX, Fig. 5.

Among the collections made at Palace Camp and Carbonado are some specimens which appear to belong to the genus *Cerithium*, one of which is represented on Plate IX. So much of the embedding material adheres to these specimens, that the aperture is obscured and the surface markings are mostly obliterated. The figure represents the largest of the specimens discovered. It is thought possible or even probable that this shell belongs to the Melaniidæ, because fossil species of *Melania* have been found elsewhere associated with unmistakably brackish-water forms, and because living species of *Melania* and *Batissa* are often found associated.

Undetermined gasteropod.—Among the specimens from Palace Camp is a fragmentary one of a gasteropod. It is much too imperfect for description, and is mentioned here only to give as full an account as possible of this small but interesting fauna.

CONCLUDING REMARKS ON THE FAUNA.

The fauna to which one instinctively turns for the purpose of zoological comparison with this Puget estuary fauna is that of the Laramie group. Such a comparison is especially suggested by the known floral relations of the two groups of strata, their presumable contemporaneity of origin, and the non-marine character of the molluscan faunas of both. Upon making a comparison, however, important zoölogical differences appear. It is true there are two species of *Corbicula* in the Puget fauna that are so closely like Laramie forms as to suggest specific identity upon casual examination, but the differences between the two faunas are strikingly shown by the family and generic characters of the other members of the Puget fauna as compared with the Laramie fauna.

For example, a species of *Teredo* has been found in the Puget group, but no member of the Teredinidæ has yet been found in the Laramie. Two species of the Puget fauna are referred to the Tellinidæ, but no member of that family has yet been found in the Laramie. But the generic form which gives an especially unique character to the Puget fauna is that of *Batissa*. This genus has not hitherto been known to occur in North America in either a fossil or living condition, nor has it been found nearer to this continent than certain of the Pacific islands. Still the hinge characters observable on these Puget estuary specimens leave no room for reasonable doubt that they are strictly congeneric with true *Batissa*. Indeed, a species of that genus which is now living upon the Fiji Islands is closely related to this fossil form.

Certain interesting relationships between Asiatic and North American faunas have been noticed by naturalists, which are recalled by this occurrence of *Batissa* in the Puget fauna. Assuming that these relationships are those of genetic succession, we naturally desire to know in which direction their lines of geographical dispersion have taken place. For example, was it towards or from the present North American continent that the dispersion of *Batissa* occurred? If it was from this continent, it is remarkable that none of its progeny have survived in any of the present continental waters, and it is equally remarkable that no evidence of its former existence in North America has been discovered except those which the Puget fauna has furnished. If the dispersion of *Batissa* was towards this continent, it seems to have only reached the present Pacific Coast region about the close of the Cretaceous period and to have then and there become extinct, while it has continued its existence on certain islands of the Pacific to the present time. But all the known facts concerning the genus *Batissa* are insufficient to throw much light upon its geological history or geographical dispersion. Even the Corbiculidæ, the family to which *Batissa* belongs, has a less completely known geological history in North America than has that of the Unionidæ.

PART V.

MESOZOIC MOLLUSCA FROM THE SOUTHERN COAST OF THE ALASKAN PENINSULA.

GENERAL REMARKS.

There has lately been received at the office of the Survey a small collection of fossils from the shores of Kialagvic, or Wrangell Bay, on the southern side of the Alaskan Peninsula, and nearly opposite the western end of Kodiak Island. They were found by one of the men employed by Messrs. Ward & Howell to make collections for their natural science establishment at Rochester, N. Y., and were sent by Mr. E. E. Howell to the Survey. Seven species are represented in this collection, all of which are apparently yet undescribed. Five of the species are Cephalopods and two are Conchifers, the genera *Ammonites*, *Baculites*, *Glycimeris ?*, and *Cucullæa* being represented.

The *Ammonites* alone give any reliable indication as to the geological age of these fossils. They are certainly of Mesozoic age, and the types to which they belong seem to indicate that they come from a formation of somewhat earlier date than the Cretaceous. One of these species belongs to the type to which Bayle gave the generic name of *Lillia*, and closely resembles *Ammonites lilli*, as figured and described by Ritter von Hauer from the northeastern Alps.[1] Another is closely related to this species, and the third belongs to the type *Amaltheus* Montfort, which is also regarded as of Liassic or of Jurassic age. While there is no reason to doubt the correctness of the information which accompanies this collection of fossils as to the locality from which they were obtained, no information as to the geology of the region was received with them. In consequence of this omission, and of the fact that all the species are regarded as new, we have no means of knowing whether or not they come from a formation which is represented by any other fossils heretofore collected in Alaska.

The only other invertebrate fossils which to my knowledge have been found in the Alaskan region, and which can be regarded as of Mesozoic age, are those which have been published by Eichwald,[2] Grewingk,[3]

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[1] Ueber die Cephalopoden aus dem Lias der nordöstlichen Alpen. Denkschr. math.-naturwiss. Classe k. Akad. Wiss., vol. 11, p. 40, pl. viii, figs. 1-3.

[2] Geognost.-paleont. Bemerkungen über die Halbinsel Mangischlak und die aleutischen Inseln, St. Petersburg, 1871.

[3] *Verhandl.* Russ. k. mineral. Gesell., pp. 344-347 pl. iv, 1848-'49.

Fischer,[1] and myself;[2] and which were collected by Doroschin, Wosnessensky, Pinart, and Dall, respectively. At least a part of the fossils collected by Doroschin, Pinart, and Dall, respectively, are shown to have come from one and the same formation by the occurrence in all of their collections of *Aucella concentrica*. This formation was referred to the Neocomian by Eichwald (op. cit.), notwithstanding the fact that other authors have usually regarded *Aucella* as a characteristic genus of the Jurassic. Eichwald also contended, in opposition to the views of many other European geologists, that the European strata which bear *Aucella* are also of Neocomian age. The occurrence of *Aucella concentrica* in the Shasta group of the California Cretaceous induced me in a former publication (op. cit.) to agree with Professor Eichwald's views as regards the Neocomian age of the Alaskan strata in question.

I do not think it impossible that the fossils which form the subject of this article belong to the same formation in Alaska which bears *Aucella concentrica*, but the two types of *Ammonites* which are found among these fossils are at least suggestive of a lower horizon. Indeed, if we had only the type character of the fossils themselves to consider, we should hardly be justified in referring them to a later age than the Jurassic.

DESCRIPTION OF SPECIES.

CONCHIFERA.

ARCIDÆ.

Genus Cucullœa Lamarck.

CUCULLÆA INCREBESCENS, sp. nov.

PLATE XIV, Figs. 5, 6.

The collection contains only a single, somewhat imperfect, left valve of this species, but its unusual shape makes it desirable to figure and briefly describe it. The valve is greatly inflated; height from base to hinge not more than half the full transverse length; the area broad, strongly concave; hinge strong. Surface marked by strong concentric lines of growth.

The only form with which it seems desirable to compare this shell is the *C. insularis* of Eichwald.[3] His figures show that the specimens of that form which were collected by Doroschin were very imperfect, and Professor Eichwald says that he himself had never seen them, but that his description was made from figures drawn under Professor Pander's direction. From Eichwald's description I am disposed to regard that form as specifically distinct from the one here described.

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[1] Voyages à la côte nord-ouest de l'Amérique, par M. Alph.-L. Pinart, pp. 33-36, pl. A.

[2] Bull. U. S. Geol. Survey No. 4, pp. 10-15, pl. vi.

[3] Figured and described in Geognost.-paleont. Bemerk. Mangischlak u. aleut. Inseln, p. 168, pl. xv, figs. 6-8.

SAXICAVIDÆ.

Genus Glycimeris Lamarck.

GLYCIMERIS? DALLI, sp. nov.

PLATE XIV, Figs. 7-9.

Shell somewhat elongate, the proportional height usually increasing with age; moderately gaping behind; test very thin; valves broadly but irregularly convex, the greatest convexity being a little in advance of the mid-length of the shell. In front of this greatest convexity there is a slight flattening of each valve, which extends from the umbones to the basal margin; umbones broad, elevated, and prominent. Beaks situated at a little less than one-quarter of the full length of the shell from the front, elevated above the hinge line, and incurved. Front margin irregularly rounded, but the front portion of each valve is obliquely truncated in front; basal margin irregularly convex by reason of the umbonal flattening of the valves, opposite which the margin is straightened or even slightly emarginate, while the greatest convexity is about mid-length; posterior margin somewhat narrowly rounded to both the dorsal and basal margins; dorsal margin behind the beaks long and nearly straight, except that it descends a little at the extremity to meet the posterior margin; dorsal margin in front of the beaks very short, the adjacent portion of each valve being so inflected as to produce the appearance of a deep lunule. Surface marked by numerous strong concentric undulations, which end upon reaching the truncated front portion of each valve, the surface of which is plain, and they also become obsolete upon the postero-dorsal region. Hinge unknown.

Length of the largest example in the collection, 57^{mm}; height of the same, 34^{mm}.

This shell has much of the general aspect of a Grammysia, but the gaping of the valves at the posterior end excludes it from that genus. Its short and truncated front is also so unusual a feature of *Glycimeris*, that, in the absence of any knowledge of its hinge, it suggests some doubt whether this shell really belongs to that genus.

The only shell with which it seems necessary to compare the one here described is the *Panopæa protracta* of Eichwald.[1] Professor Eichwald's figures, however, show that the beaks of his species are nearly centrally situated, while in this species they are quite near to the front. His species also does not show the obliquely truncated front, with its plain surface, which is a conspicuous character of the form here described. Professor Eichwald's specimens came from the "Schwarzen Neokomkalke von Alaska," where they were associated with numerous other species, all of which are different from any of the species described in this article. The specimens of this species came from a greenish sandstone, in which it was associated with all the species noticed in this article, none of which are recognized as identical with any other species yet found in the Alaskan region. The specific name is given in honor of Dr. W. H. Dall, the author of Alaska and its Resources.

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[1] *Geognost.-paleont.* Bemerk. Mangischlak u. Aleut. Inseln, p. 160, pl. xiii, figs. 8, 9.

CEPHALOPODA.

BELEMNITIDÆ.

Genus Belemnites Lamarck.

BELEMNITES ——?

PLATE XIII Fig. 6.

The collection contains a considerable number of fragments of *Belemnites*, but there are no specimens among them which are even approximately perfect. The greater part of them belong to a species which was evidently a very long and slender one, and which had a moderately long phragmocone. The largest example referable to this species has a diameter at about the mid-length of the phragmocone of about 12^{mm}. The full length of an example having such diameter was apparently not less than 130^{mm}.

BELEMNITES ——?

PLATE XIV, Fig. 4.

The collection also contains portions of very large phragmocones of a Belemnite which are more or less distorted by pressure, and which are believed to represent a different species from that which is represented by the fragments before referred to. The diameter of the largest example in the collection is 38^{mm}, and the chambers were about 5^{mm} in thickness; the septa were broadly concavo-convex and apparently very thin. The apical angle of the phragmocone appears to have been comparatively short, but the specimens are too imperfect to ascertain the angle. The collection contains no fragments of the shaft of this species.

AMMONITIDÆ.

Genus Ammonites (Lillia Bayle), Bruguière.

AMMONITES (LILLIA) HOWELLI, sp. nov.

PLATE XII, Figs. 1, 2, and PLATE XIV, Figs. 1–3.

Shell reaching a moderately large size, discoid, broadly umbilicate; each volution embracing about one-half the width of the next one within, but the minute earlier volutions embrace a less proportion of the width of the adjacent one than do the later volutions; transverse section of the volutions ovate, the diameter which lies in the plane of the coil, being about one-quarter greater than the transverse, but the difference is less than this in the small earlier volutions; the transverse diameter of the volutions is a little greatest near the umbilical side; their sides broadly convex and rounded into the umbilicus; the peripheral side regularly rounded in the case of exfoliated specimens, especially of the smaller volutions, but the larger volutions, when the shell substance is retained, show a low, rounded, peripheral ridge, with a narrow, flattened, or slightly concave space at each side of it. This ridge is apparently formed of the shell substance alone, and when the latter cleaves off from the periphery of the chambered volutions the siphuncle is more or less exposed; sides of the volutions distinctly marked by transverse ribs, the principal ones of which end a little before reaching the umbilical margin on the one hand, and just before reaching the peripheral ridge on the other. Between each two of the principal ribs (that is, those which cross the entire side of the volutions) there are one, two, or rarely three short or accessory ribs, which arise near or a little beyond the middle of the side and end near the periphery, where they are of uniform size and outward extension with the principal ribs. The ribs are therefore more than twice as numerous upon the peripheral half of the volutions as they are upon the umbilical half. The direction of the ribs across the volutions is nearly transverse, but they are usually directed a little forward. The principal ribs alone are seen upon the inner volutions, because the accessory ribs and the outer half of the principal ones are entirely covered by the next succeeding volution. The umbilical half of the principal ribs is stronger and more prominent than the peripheral half, but they are apparently never spinous. The septa are very complex; a plan of one of them is given on Plate XIV, Fig. 3. The living chamber constituted fully two-thirds of the last volution. Character of the aperture unknown.

This shell bears much resemblance to *Ammonites lilli* Hauer, from the Lias of the northeastern Alps, which is the type of Bayle's genus *Lillia*; but the volutions are a little more embracing than they are in that species and their increase in size with the growth of the shell is *proportionally* greater. *A. lilli* is also nearly or quite without the accessory ribs which form a conspicuous feature of the Alaskan species.

The collection contains a considerable number of this species, but they are mostly small. The largest one measures upward of 150^{mm} in diameter of the coil. The specific name is given in honor of Mr. E. E. Howell, formerly of the U. S. Geological Survey.

AMMONITES (LILLIA) KIALAGVIKENSIS, sp. nov.

PLATE XIII, Fig. 7.

Shell closely resembling that of the preceding species in general form and aspect; broadly umbilicate; each volution embracing less than one-half the next preceding one; transverse section of the volutions elliptical, the diameter which lies in the plane of the coil, being about one-quarter greater than the transverse; sides of the volutions broadly convex, rounded somewhat abruptly into the umbilicus; peripheral side somewhat regularly rounded, but bearing a narrow, slightly raised median ridge; sides of the volutions marked by flexuous ribs, a little less than half of which become obsolete upon the umbilical border and the remainder become obsolete between the middle and that border. All of them end in a very slight enlargement just before reaching the peripheral ridge. A forward curve of the ribs from the umbilical border occupies a little more than the inner half of the side of the volution, and a less distinct backward curve occupies the outer portion. The living chamber occupies about three-quarters of the last volution. Character of the septa and of the aperture unknown.

The collection contains only two examples of this species, both of which are imperfect. The larger one has a diameter of coil of only 55^{mm}, but it is likely that fully mature shells were much larger. The proportions of its volutions, as well as the general aspect of the shell, are closely like those of the preceding species, and the difference between the two species is more conspicuously seen with reference to the ribs which traverse the volutions. In this species the ribs are distinctly flexuous; the accessory ribs are fewer in number than in *A. Howelli*, and their greatest prominence is at the peripheral end of the principal ribs, instead of being at the umbilical end, as it is in *A. Howelli.*

AMMONITES (AMALTHEUS) WHITEAVESII, sp. nov.

PLATE XIII, Figs. 1-5.

Shell discoid; umbilici small, and sharply defined by the elevation of the border; volutions so much embracing, that only a little of each of the inner volutions is visible within the umbilici; sides of the volutions broadly convex, the inner half descending only slightly toward the umbilicus, at the border of which it is abruptly raised in the form of a narrow rounded ridge; the sides of the umbilicus descend perpendicularly within until they reach the next preceding volution; periphery bearing a prominent, plain, hollow keel, which is constructed of shell substance, a layer of the same being between the small cavity of the keel and that of the body of the shell; and no trace of the keel appears upon specimens from which the shell substance has been removed; sides marked by moderately elevated, rounded ribs, which become obsolete upon reaching the raised umbilical border on the one hand and the peripheral keel on the other; they are slender and close together toward their thin inner ends, but are broader and farther apart toward their peripheral ends. From the raised umbilical border the ribs are directed obliquely forward in almost a straight line, and just before reaching the middle of the side of the volution they bend somewhat abruptly backward, and just before reaching the peripheral side they bend forward again by a nearly regular curve, and become obsolete upon the periphery. Septa complex, a plan of one of which is figured on Plate XIII, Fig. 5. Aperture and extent of the living chamber unknown. Diameter of the coil at the posterior end of the living chamber of the largest example in the collection, including the peripheral ridge, 93^{mm}; greatest diameter upon the same line, measured through the umbilical ridges, 23^{mm}.

The general aspect of this species is much like that of *A. Breweri* Gabb, from the Shasta group of California; but it differs in having a prominent peripheral keel, a narrower umbilicus, a raised umbilical border, and also in other details of form and structure.

The peripheral keel of this species is not crenulated, as it usually is in *Amaltheus*, and the septa are more complex; but in essential characters it agrees with the diagnosis of that genus as emended by Professor Zittel in his Handbuch der Paleontologie.

The specific name is given in honor of Mr. J. F. Whiteaves, paleontologist to the Geological Survey of Canada.

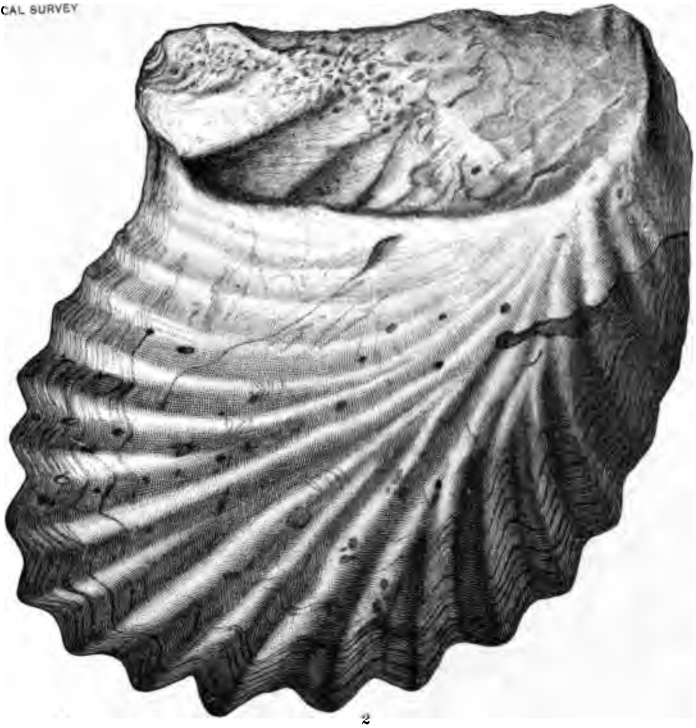
PLATES.

PLATE I.

PLATE I.

OSTREA DILLERI (page 14).

FIG. 1. Exterior view of a lower valve, natural size.
2. Exterior view of an upper valve.
For interior views of these specimens, see Pl. II.



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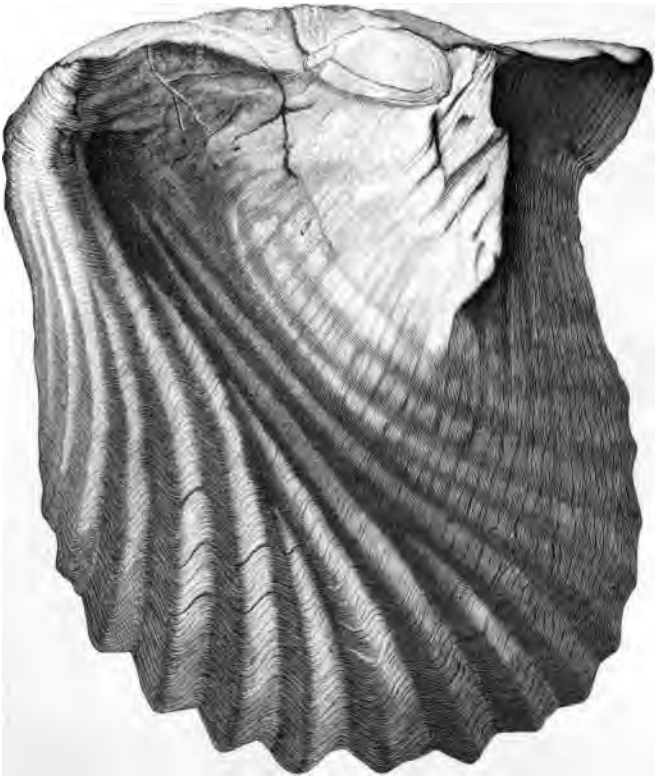

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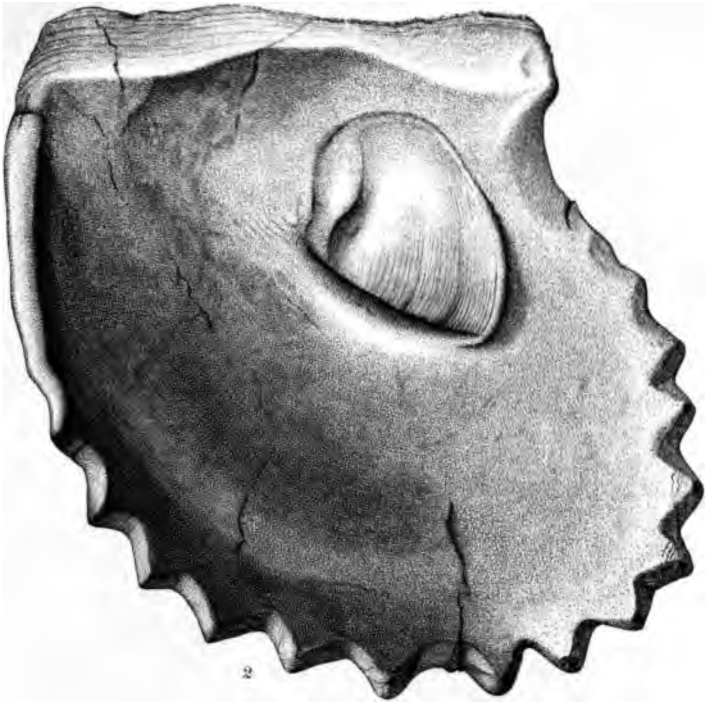
Ostrea Dilleri.

PLATE II.

OSTREA DILLERI (page 14).

FIG. 1. Interior view of the specimen represented by Fig. 1, Pl. I.
2. A similar view of the specimen represented by Fig. 2, Pl. I.
For exterior views of these specimens, see Pl. I.



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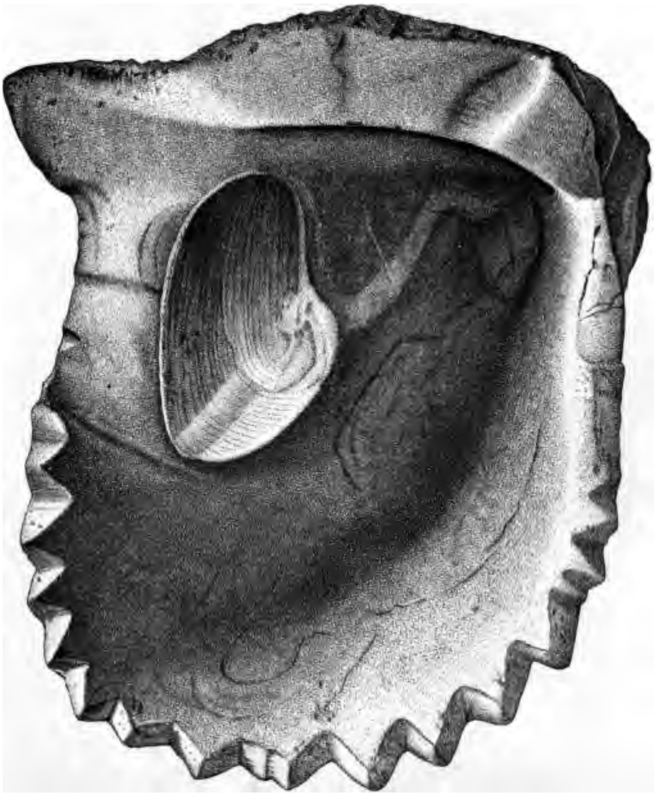

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Ostrea Dilleri.

PLATE III.

PLATE III.

FULGURARIA GABBI (page 23).

FIG. 1. Apertural view of a large example. Nearly the whole outline of the inner lip is obscured by adhering rock.

FULGUR HILGARDI (page 22).

2. Lateral view of an adult example.
3. Opposite view of the same example.

TROPHON CONDONI (page 21).

4. Lateral view of a medium-sized example.
5. Opposite view of the same example.

CANCELLARIA TURNERI (page 25).

6. Lateral view of an adult example.
7. Opposite view of the same example. The specimen has been much exfoliated, destroying the surface markings.

GYRODES DOWELLI (page 19).

8. Lateral view of an adult example.
9. Opposite view of the same example. The specimen has been slightly compressed obliquely.

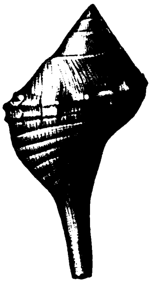
RIMELLA MACILENTA (page 19).

10. Lateral view of an example not quite mature.
11. A mature example, with outlines showing the shape of the outer lip and of the posterior canal.
12. A natural cast, showing a part of the posterior canal.

CERATIA NEXILIA (page 21).

13, 14. Opposite lateral views of a medium-sized example.

All the figures on this plate are of natural size.



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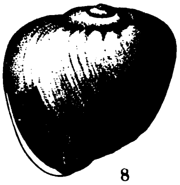

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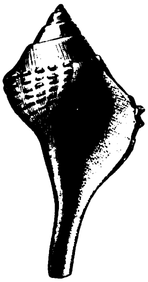

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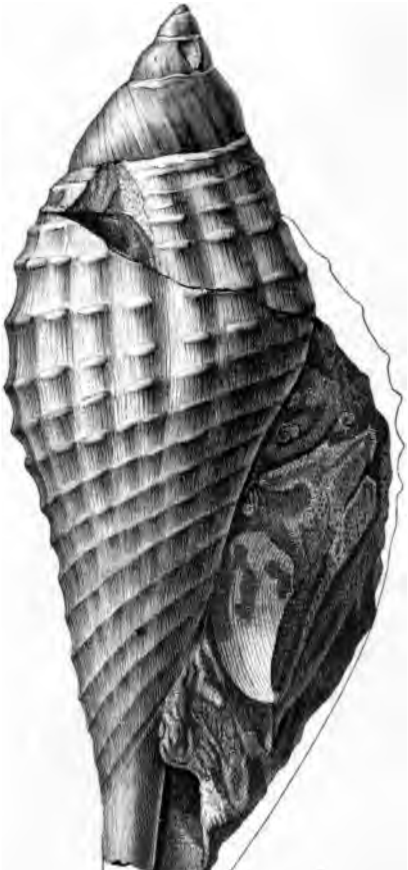

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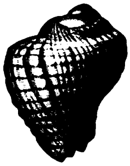

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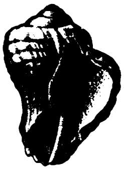

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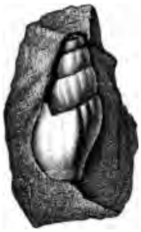

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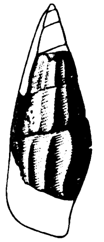

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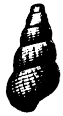

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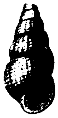

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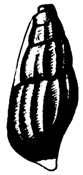

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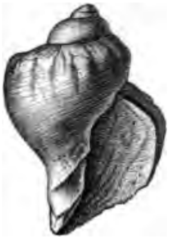

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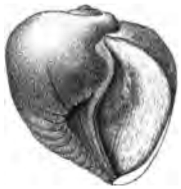

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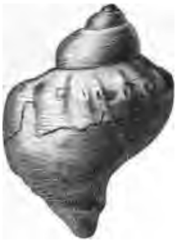

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1. Fulguraria Gabbi
2, 3. Fulgur Hilgardi.
4, 5. *Trophon Condoni.*
6, 7. *Cancellaria* Turneri.

8, 9. Gyrodes Dowelli.
10, 11, 12. Rimella macilenta.
13, 14. Ceratia nexilia.

PLATE IV.

PLATE IV.

SCOBINELLA DILLERI (page 25).

FIG. 1. Lateral view of an example having unusually strong surface markings.
2. A similar view of another example showing the notch of the outer lip.
3. An imperfect example showing the three strong columellar folds.
All natural size.

COMINELLA LECONTEI (page 22).

4. Lateral view of an adult example.
5. Opposite view of another example. Natural size.

MESALIA OBSUTA (page 20).

6. Lateral view of a somewhat slender example.
7. Opposite view of another example. Natural size.

TROCHUS (ANADEMA) GEMIFERUS (page 17).

8. Lateral view of a partially compressed example.
9. Basal view of the same example. Natural size.

STOMATIA OBSTRICTA (page 18).

10. Lateral view of a partially exfoliated example.
11. Opposite view of another example. Natural size.

FAUNUS MARCIDULUS (page 20).

12. Lateral view of the type specimen.
13. Opposite view of the same. Enlarged.

LYSIS OPPANSUS (page 17).

14. Lateral view of a natural cast, somewhat compressed.
15. Apical view of the same. Natural size.

ACTÆON INORNATUS (page 15).

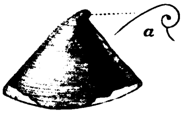
16. Lateral view; enlarged.
17. Opposite view of the same, the columellar fold not shown.
18. Another example, the outer lip broken away, showing the fold.

VASCULUM OBLIQUUM (page 16).

19. Lateral view, the coil of the apex shown at *a*.
20. Posterior view of the same example.
21. Apical view of the same example. Natural size.

ZIRPHÆA PLANA (page 15).

22. Right valve. Natural size.



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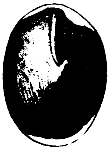

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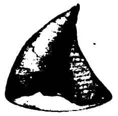

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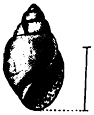

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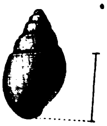

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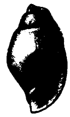

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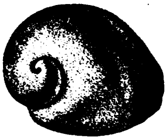

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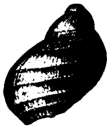

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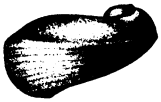

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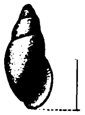

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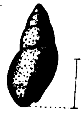

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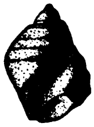

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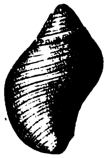

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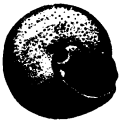

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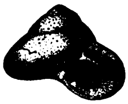

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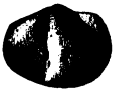

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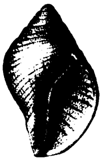

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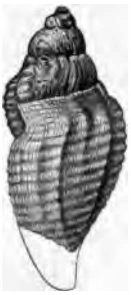

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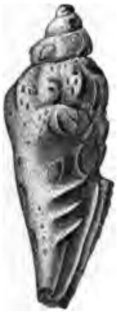

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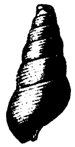

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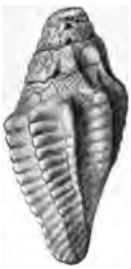

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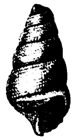

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1-3. Scobinella Dilleri.
4, 5. *Cominella LeContei.*
6, 7. Mesalia obsuta.
8, 9. Trochus gemiferus.
10, 11. Stomatia obstricta.

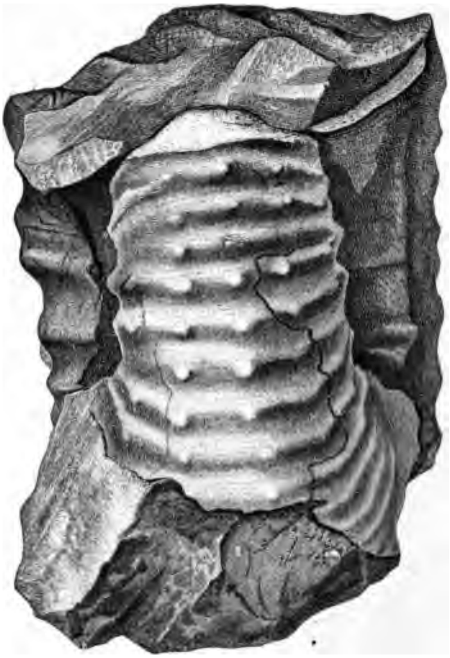
12, 13. Faunus marcidulus.
14, 15. Lysis oppansus.
16, 17, 18. Actæon inornatus
19, 20, 21. Vasculum obliquum.
22. Zirpnæa plana.

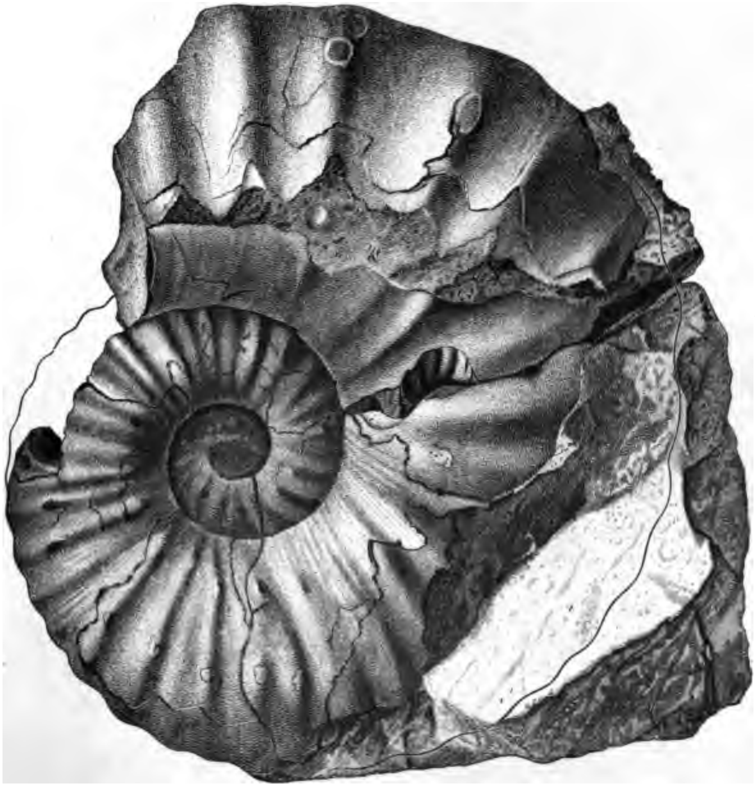
PLATE V.

PLATE V.

AMMONITES TURNERI (page 26).

FIG. 1. Lateral view of the type specimen.
2. Peripheral view of the same. Natural size.





1

Ammonites Turneri.

PLATE VI.

PLATE VI.

ANATINA SULCATINA? (page 43).

FIG. 1. Right side view of a large example.

CRASSATELLA TUSCANA (page 39).

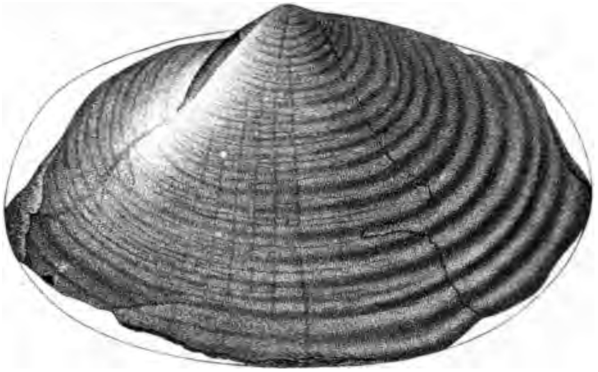
2. Left side view of a medium sized example.
3. Dorsal view of the same example.
4. View of the hinge of a right valve.

CLISOCOLUS DUBIUS (page 41).

5. Lateral view of an imperfect example.
6. Dorsal view of the same.
7. Front view of the same.

CLISOCOLUS CORDATUS (page 41).

8. Lateral view of an imperfect example of a left valve.
9. Front view of the same.



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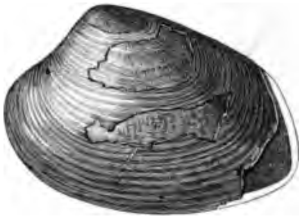

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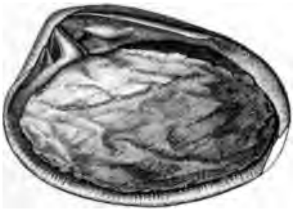

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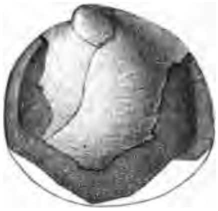

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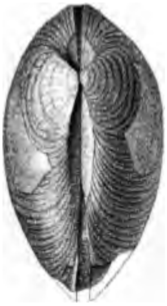

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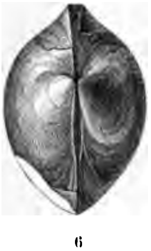

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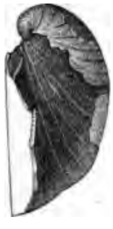

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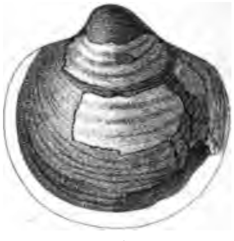

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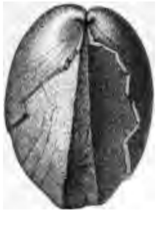


7

1. Anatina sulcatina. ?
2–4. *Crassatella tuscana.*

5–7. Clisocolus dubius.
8, 9. Clisocolus cordatus.

PLATE VII.

PLATE VII.

PERNA EXCAVATA (page 37).

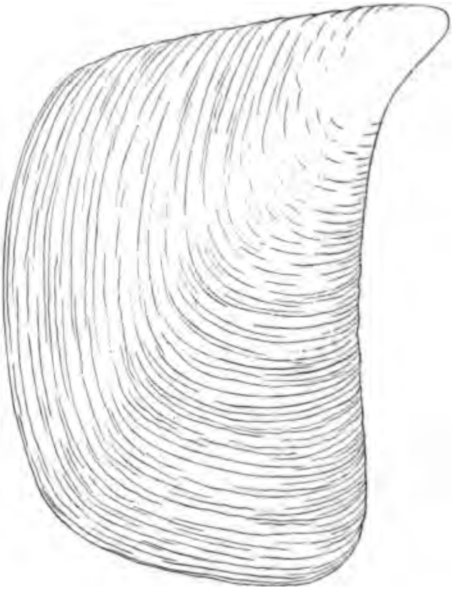
FIG. 1. Outline view of right valve. A restoration from numerous imperfect examples. Natural size.

AMMONITES MACLUREI (page 48).

2. Lateral view of a fragment.
3. Outline of a transverse section of the living chamber.
Both natural size.

VANIKOROPSIS SUCIENSIS (page 46).

4. Lateral view; enlarged.



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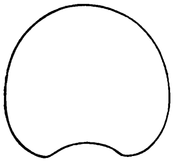

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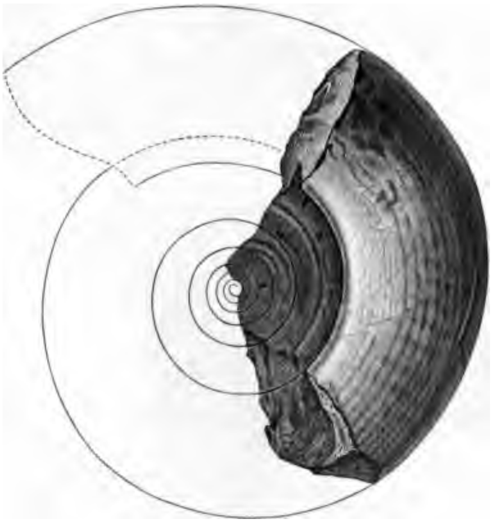

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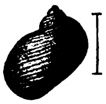


4

1. Perna excavata.
2, 3. Ammonites Maclurei.

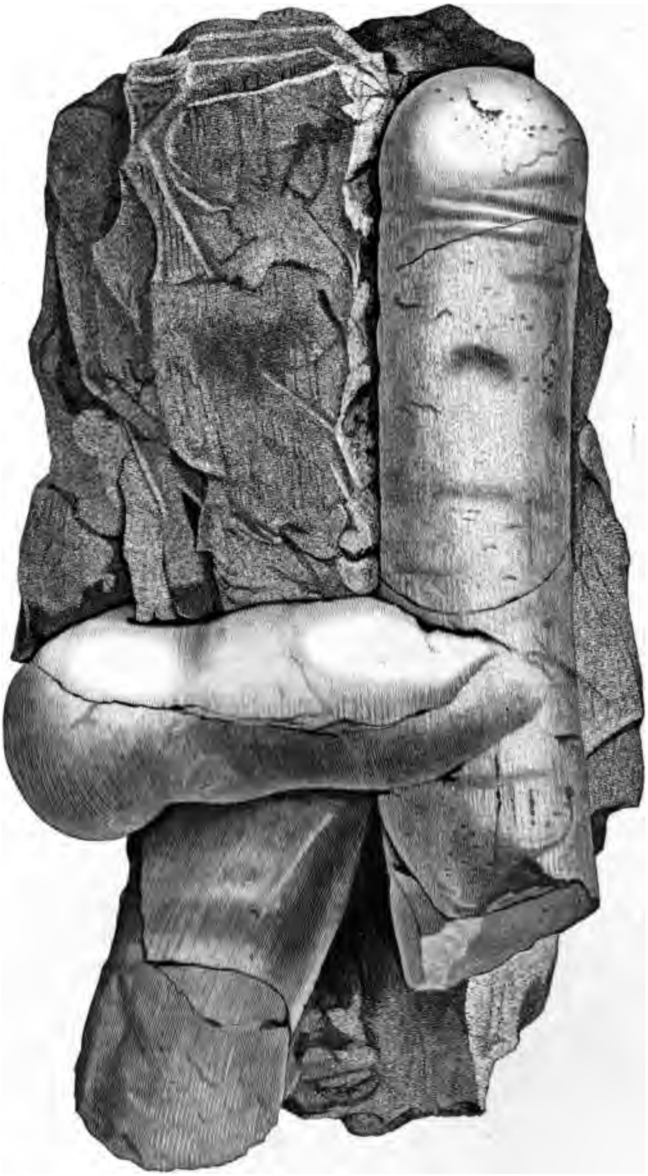
4. Vanikoropsis suciensis.

PLATE VIII.

PLATE VIII.

TEREDO PUGETENSIS (page 62).

A mass of petrified wood, showing the large borings. Natural size.



Teredo pugetensis.

PLATE IX.

PLATE IX.

BATISSA NEWBERRYI (page 60).

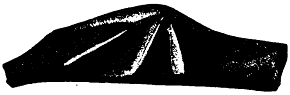
FIG. 1. Lateral view of a right valve.
2. Left side view of an imperfect specimen, the beak of the left valve being broken away, showing the broad cardinal teeth of the right valve.
3. A gutta-percha cast of the cardinal portion of the hinge of Fig. 2, showing the narrow teeth of the left valve.
All of natural size.

CARDIUM (ADACNA ?)——— ? (page 58).

4. Lateral view of a natural cast. Natural size.

CERITHIUM ?——— ? (page 58).

5. Lateral view. Natural size.



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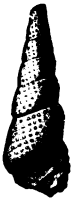

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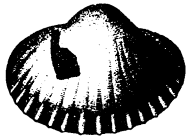

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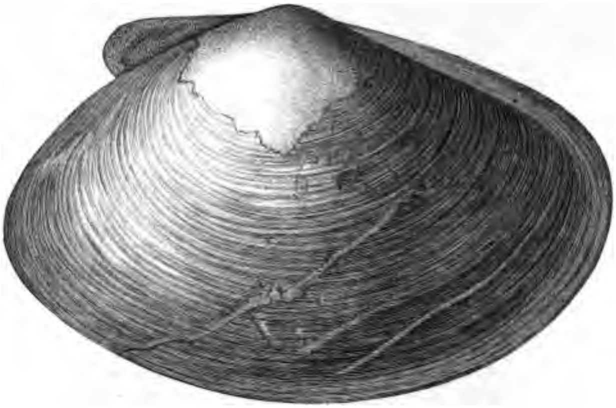

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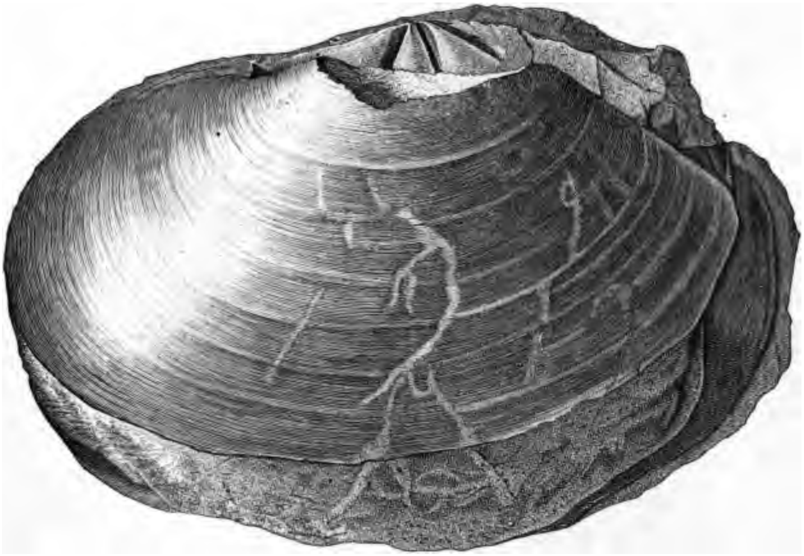

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1–3. Batissa Newberryi.
4. *Cardium* (*Adacna* ?) ——— ?

5. Cerithium? ———?

PLATE X.

PLATE X.

SANGUINOLARIA ? CAUDATA (page 61).

FIG. 1. Right side view of an example, the posterior end of which is only slightly elongated.
2. An imperfect example, the posterior end being more elongated.
3. Another imperfect example, showing the posterior end greatly elongated.

PSAMMOBIA OBSCURA (page 61).

4. Left side view of an imperfect example.
5. Right side view of another imperfect example.
6. An imperfect natural cast, showing the pallial line and sinus and posterior muscular scar.

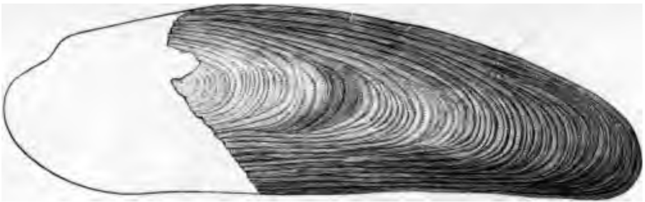
CYRENA BREVIDENS (page 58).

7. Lateral view of a right valve.
8. A similar view of another right valve.
9. A more elongate example; left valve.
10. An imperfect example, showing the hinge of the right valve and the pallial line.
11. A similar view of another example, showing the hinge of the left valve.

NERITINA ——— ? (page 62).

12. View of the upper side of a natural cast.

All figures on this plate are of natural size.



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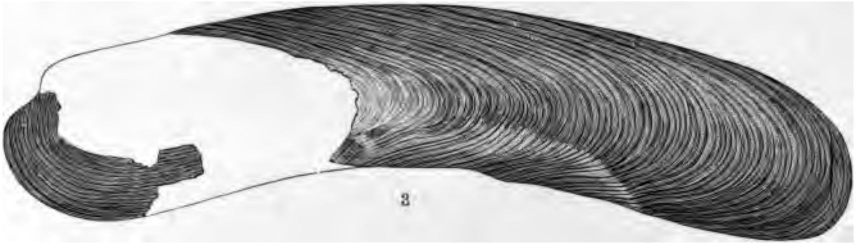

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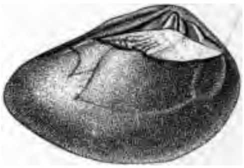

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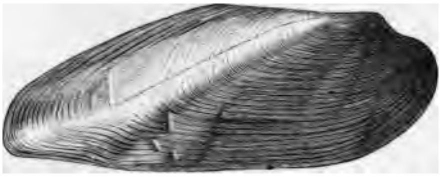

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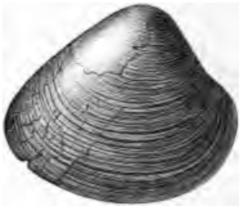

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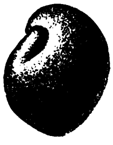

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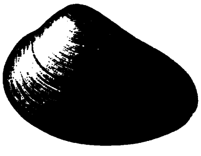

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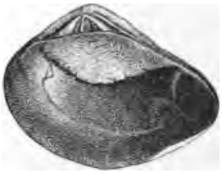

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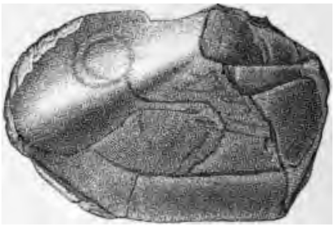

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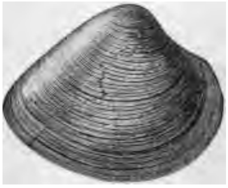

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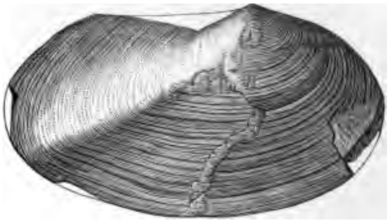

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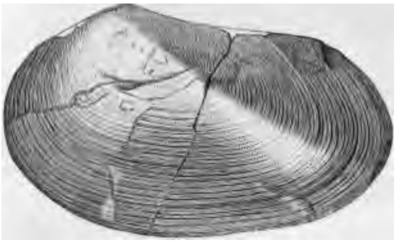

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1–3. *Sanguinolaria ? caudata.*
4–6. *Psammobia obscura.*

7–11. Cyrena brevidens.
12. Neritina ——?

PLATE XI.

PLATE XI.

BATISSA DUBIA (page 61).

FIG. 1. An imperfect natural cast.
2. A still more imperfect natural cast, but one which shows the large external ligament.

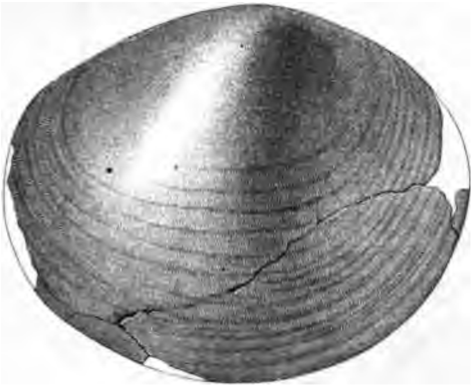
CORBICULA WILLISI (page 59).

3. A large left valve.
4. A smaller right valve.
5. A still smaller left valve.
6. An imperfect left valve, showing the cardinal and anterior lateral teeth.
7. A fragment of a right valve, showing the hinge nearly complete.

CORBICULA PUGETENSIS (page 60).

8. Lateral view of a right valve.

All the figures on this plate are of natural size.



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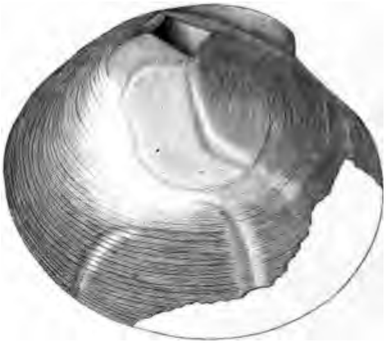

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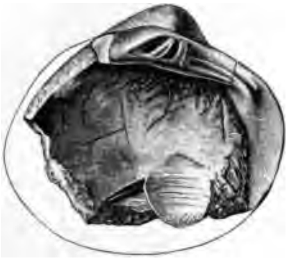

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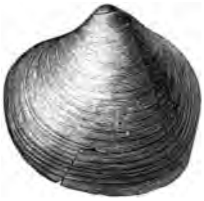

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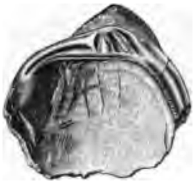

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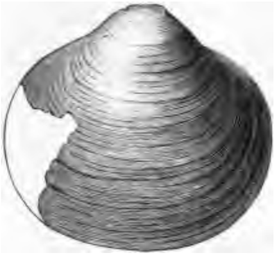

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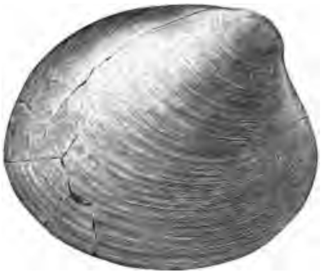

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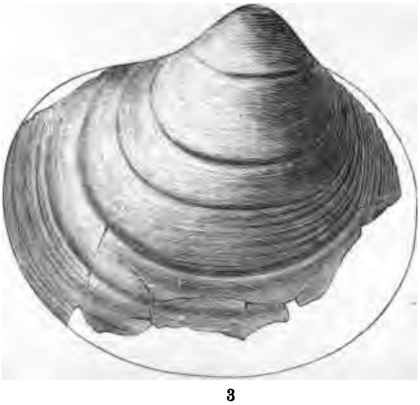


3

1, 2. Batissa dubia.
3-7. Corbicula Willisi.

8. Corbicula pugetensis.

PLATE XII.

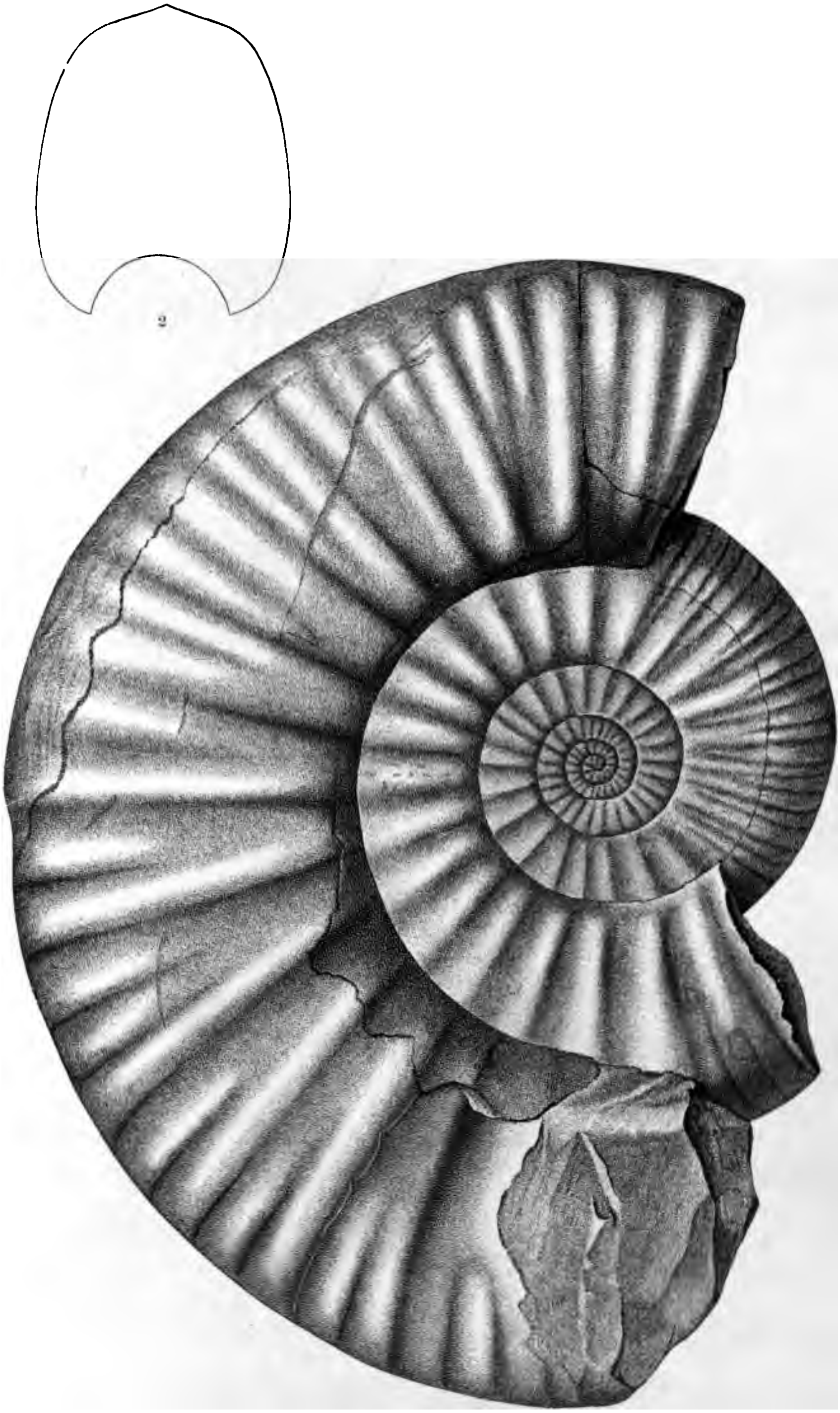
PLATE XII.

AMMONITES HOWELLI (page 68).

FIG. 1. Lateral view of a broken example. All that is shown of the outer volution belongs to the living chamber. Natural size.

2. Outline of a transverse section of the outer volution of Fig. 1. A similar outline of the inner volutions have a different shape, as is indicated by Fig. 2, Pl. XIV.

For other figures of this species, see Pl. XIV.



1, 2. Ammonites Howelli.

PLATE XIII.

AMMONITES WHITEAVESI (page 69). [illegible]

Fig. 1. Lateral view of an example from which the living chamber has been all broken away.
2. Peripheral view of the same example in outline.
3. Diagram showing the hollow character of the peripheral keel.
4. Lateral view of a small example of this species.
5. Diagram of one of the septa of Fig. 4, enlarged.

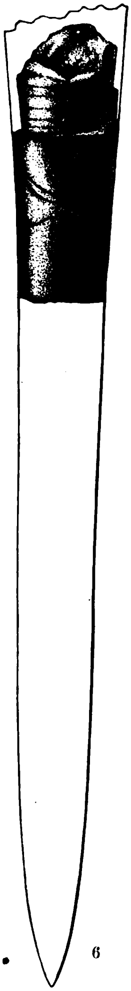
BELEMNITES ———? (page 67).

6. A fragment showing part of the phragmocone; and added outline showing the length of the shaft, as indicated by other fragments.

AMMONITES KIALAGVIKENSIS (page 69).

7. Lateral view of an imperfect example.

All the figures on this plate are of natural size, except Fig. 5.



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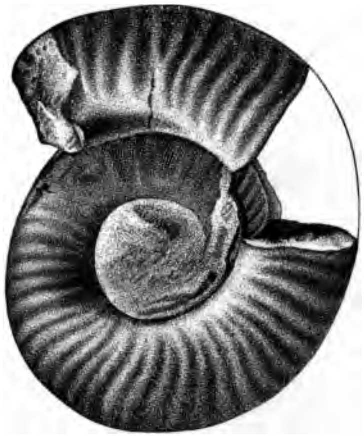

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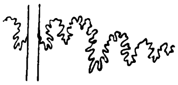

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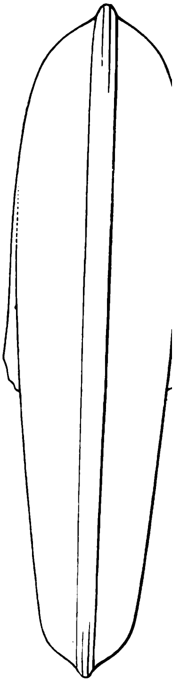

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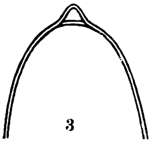

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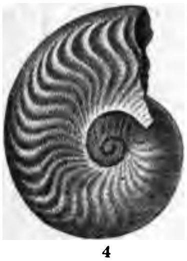

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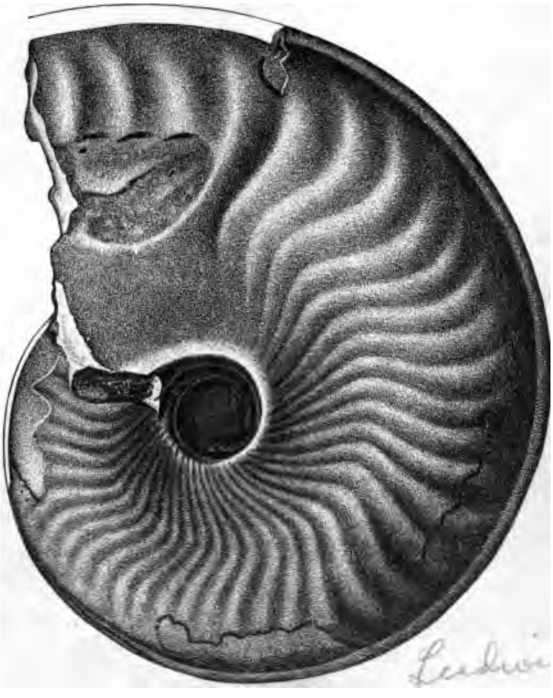


1

1–5. Ammonites Whiteavesi.
6. Belemnites ——— ?

7. Ammonites kialagvikensis.

PLATE XIV.

PLATE XIV.

AMMONITES HOWELLI (page 6[illegible]).

Fig. 1. Lateral view of an example showing only inner volutions.
2. An outline peripheral view of the same example.
3. Diagram of one of the septa of an example having about the size of Fig. 1; enlarged.

For other figures of this species, see Plate XII.

BELEMNITES ——— ? (page 67).

4. A fragment of a large phragmocone, which has been somewhat compressed.

CUCULLÆA INCREBESCENS (page 65).

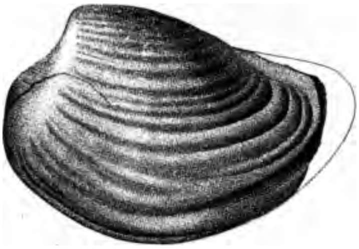
5. Lateral view of an imperfect left valve.
6. A front view of the same, with a diagram of the opposite valve, showing the great transverse depth of the valves.

GLYCYMERIS? DALLI (page 66).

7. Lateral view of a left valve.
8. A similar view of another left valve.
9. Right side view of a small example.

All the specimens are in the condition of natural casts.

All the figures on this plate are of natural size, except Fig. 3.



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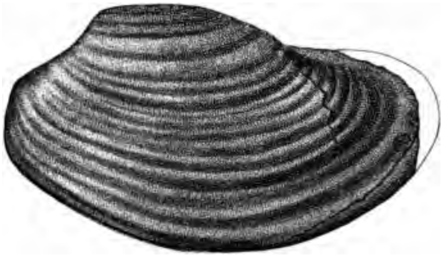

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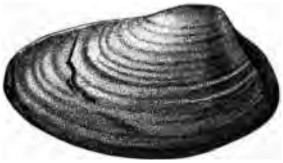

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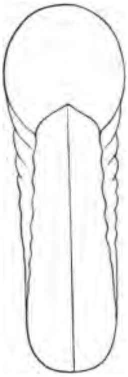

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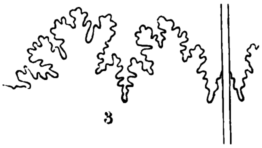

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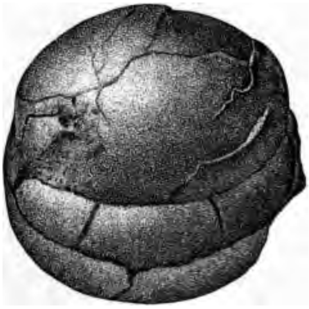

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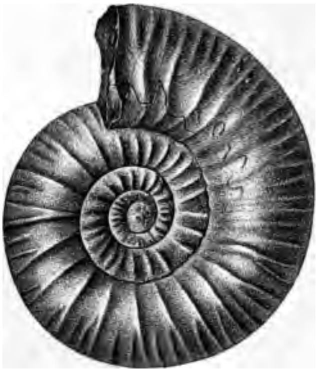

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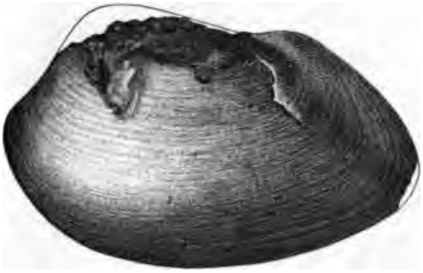

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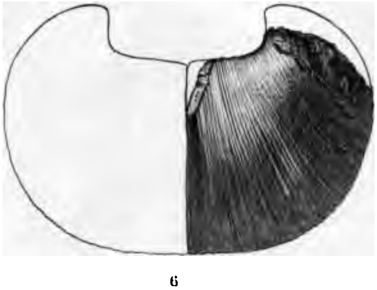

6

1-3. Ammonites Howelli.
4. Belemnites ——— ?

5, 6. Cucullæa increbescens.
7-9. Glycimeris ? Dalli.

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UNITED STATES GEOLOGICAL SURVEY

No. 52

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1889

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

SUBAËRIAL DECAY OF ROCKS

AND

ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS

BY

ISRAEL COOK RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1889

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LETTER OF TRANSMITTAL.

Department of the Interior,
U. S. Geological Survey,
Washington, D. C., October 12, 1888.

Sir: The observations on which the conclusions presented in the following pages are based were made principally during the summers of 1885, 1886, and 1887, in the Appalachian region south of Pennsylvania. This paper was presented for publication in the fall of 1887, but owing to a delay in printing I have been enabled to revise it during the present month and include certain observations made during the past summer.

In April, 1885, I began geological field work at Knoxville, Tenn., and traveled eastward across the Appalachians to Chester, S. C., whence my investigations led me northward through North Carolina and Virginia to the Potomac River. This field work lasted until late in October and enabled me to visit all of the areas occupied by rocks of the Newark system south of the Potomac, which were my special subject of study. In April, 1886, I resumed field work at Leesburg, Va., where I had disbanded my party the previous October, and carried examinations as far north as the Pennsylvania-Maryland boundary. As it was not deemed advisable to continue the study of the Newark system until satisfactory maps could be had of the regions it occupies, a field for geologic work was assigned me in Alabama and Georgia.

To reach this field I made a journey through the great valley which skirts the Appalachian Mountains on the west. As this valley is a marked feature, both topographically and geologically, all the way from New York to central Alabama, and is an important part of the Appalachian uplift, I shall speak of it in its entirety as the Great Appalachian Valley—a name applied to it by W. B. Rogers in discussing the physical structure of the Appalachians, and adopted by Arnold Guyot and others. In my journey south I traversed this valley, with various departures to points of geological interest, from Pennsylvania to central Alabama, having always in mind various problems relating to the subaërial decay of rocks. Finally, late in the season, my work led me into central and northern Georgia, where an opportunity was presented for observing the decay of the crystalline rocks forming the extreme southern end of the Appalachians.

In the spring of 1887 I resumed field work in Alabama and Georgia, and spent five months in the completion of a geologic section 30 miles broad, extending from the undisturbed carboniferous rocks of northwestern Alabama to the metamorphic schists of central Georgia. While traveling by rail to begin this work I stopped at Charlottesville, Va., Greenville, S. C., and Atlanta, Ga., for the purpose of examining the residual deposits at those localities.

The results of my observations during these various journeys, so far as they relate to the subaërial decay of rocks, are here presented. This subject was incidental to other geologic work, and was not the prime object of the journeys mentioned; yet it claimed a large share of attention for the reason that the records of decay are everywhere to be seen, not infrequently to the entire concealment of the general geology of the country. The journeys mentioned were made on horseback and on foot, with the aid of camping outfit, thus securing unusual advantages for observation. I record the manner of traveling and the routes followed in order to indicate to some extent the character of my observations, as well as the degree of confidence to be placed in the conclusions drawn from them.

The field season just closed necessitated a journey through portions of Colorado, New Mexico, Arizona, California, Nevada, Wyoming, and Dakota, during which the various questions relating to the disintegration and decay of rocks received as much attention as could be given them without detriment to other work.

I remain, very respectfully,

ISRAEL C. RUSSELL,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

SUBAËRIAL DECAY OF ROCKS AND ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS.

By Israel C. Russell.

INTRODUCTION.

In Part I of this paper attention is directed to the widespread decay of the surface rocks throughout the Appalachian region south of the southern limit of the glaciated area of northeastern America. It is shown also that rock decay is far more advanced in the southern than in the central and northern Atlantic States and increases gradually southward. This variation is thought to be due to climatic causes, combined with recent orographic movements which have accelerated denudation in the northern portion of the region under discussion. From a brief review of geographical distribution of residual deposits in various regions, together with other considerations, the conclusion is drawn that rocks decay most rapidly in warm, humid climates.

In Part II it is shown that iron-stained sands resulting from the subaërial decay of crystalline rocks agree in many ways with the similarly iron-stained sands forming certain geologic formations, of which the sandstones of the Newark system are an example. This, in connection with other facts, leads to the hypothesis that certain sandstones and shales, the grains of which are covered with ferruginous incrustations, received their red color during the subaërial decay of the rocks from which they were derived.

The name Newark system, proposed by W. C. Redfield in 1856, is adopted in this paper instead of Triassic, Jurassic, Jura-Trias, etc., to designate the formation composed mainly of red sandstones and shales, which occurs in detached areas along the Atlantic border from Nova Scotia to South Carolina.[1]

The bibliography at the end of this paper contains a list of publications consulted relating to the decay of rocks.

---

[1] Reasons for using this name are given in The American Geologist, vol. 3, 1889, pp. 178–182.

I. SUBAËRIAL DECAY OF ROCKS.

The formation of soils by the decomposition of rocks in place has already received a large share of attention, but recent observations suggest that changes of this nature have a wider geological bearing than has generally been assigned them, and that questions relating to the origin and distribution of soils and subsoils may still be discussed with profit.

DECAY OF THE CRYSTALLINE ROCKS OF THE PIEDMONT REGION.

In traveling south from the southern margin of the moraines left by the Pleistocene ice sheet of northeastern America, along the belt of crystalline rocks bordering the Appalachian Mountains on the east, the surface exposures exhibit greater and greater evidences of decay as one proceeds.[1] In Pennsylvania and Maryland the mica schists and allied rocks are frequently disintegrated to a depth of many feet, so that they may be removed with a pick and shovel. The strata, however, are for the most part simply broken down, so far as is apparent to the eye, although chemical alteration, especially of the feldspars, has unquestionably occurred. With the exception of a few feet at the surface, however, it is principally disintegration, not decomposition, that has taken place. In a handful of fragments the eye immediately determines the character of the rock from which they were derived; if chemical change was far advanced this would not be the case. It is difficult to ascertain the depth of this alteration, but in general it may be taken at from fifteen to thirty feet; localities are not uncommon, however, where well-marked disintegration has reached a depth of fully 50 feet below the surface. Typical examples of residual clay—the extreme result of subaërial decay—are not common in this portion of the Appalachian belt, but may occasionally be seen in railroad cuts and similar excavations.

As one travels south from the Potomac a great increase is seen in the extent and in the depth of the chemical changes that have affected the outcrops. Throughout nearly the entire area underlaid by crystalline rocks in Virginia and the Carolinas east of the Blue Ridge the soil is red clay, which is a residual deposit produced by the subaërial alteration of the rocks on which it rests. Over large areas this alteration reaches more than a hundred feet below the surface, but, owing to lack of exposures, its full extent is seldom seen.

---

[1] The observations on the decay of rocks presented in this paper refer principally to changes that are obvious to the eye, and not to the alterations frequently detected when thin sections of apparently sound rocks are examined with a microscope.

The depth at which decayed rocks have been observed assures us that the downward limit of the changes produced in rocks by atmospheric agencies is not always determined by the level of stream erosion, or even by the horizon of the ocean surface. This may perhaps be due to recent subsidence, which has depressed the decayed rocks below the level at which the alteration took place, for it is evident that the changes due to atmospheric influences are of a different character from those produced by the circulation of water through rocks at great depth, although there is no sharp line of demarkation between the two processes.

In cuts along the line of the Carolina Central Railroad east of Wadesborough, on the Cape Fear and Yadkin Valley Railroad near Jonesborough, and along the North Carolina Railroad west of Raleigh, N. C., fine sections of decomposed crystalline rocks are exposed. These are but isolated examples, however, of what can be seen over thousands of square miles in the great area of crystalline rocks in which they are situated.[1] At the localities cited above the rocks retain little of their original character, but are now variously colored clays, which, when moist, can be molded in the fingers or cut with a pocket-knife. In many places the layers of granite, mica schist, hornblende schist, talcose schist, and similar rocks have been twisted and folded so that in their present eroded condition the bedding in the outcrops is nearly perpendicular. In such instances, when the rock is excavated, as in railroad cuts (the best example I observed is at Cary, eight miles west of Raleigh), the entire mass, to a depth exceeding fifty feet, is a soft, plastic clay, which reveals its original stratification and lamination by an almost infinite number of vertical bands and lines of various tints and shades. Bright red and brilliant yellow predominate, but these harlequin tints are many times blended with gray, purple, and white in such a way as to produce most remarkable examples of natural coloring. An analysis of a characteristic sample of this residual clay, apparently derived from chloritic schist, gave the following result:

Analysis of residual clay. By R. B. Riggs.

Silica (SiO_2)	54.54
Alumina (Al_2O_3)	26.43
Ferric oxide (Fe_2O_3)	9.04
Water (H_2O)	9.87
Total	99.88

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[1] Other localities have been noted by L. S. Burbank, Proc. Boston Soc. Nat. Hist., vol. 16, pp. 150–155; and by W. C. Kerr, Am. Jour. Sci., 3d series, vol. 21, 1881, pp. 345–358. The formation of soils by the decomposition of crystalline rocks in Alabama has been well described by Eugene A. Smith in the Geol. Survey Alabama, Rept. for the years 1881 and 1882; and by William C. Stubbs in Berney's Handbook of Alabama, pp. 147 et seq.

About Greenville, S. C., the character of the residual deposits resulting from the subaërial decay of highly micaceous gneiss may be observed. The deep-red color of the plowed fields, merging at times into broad areas of yellow, to be seen in early spring, together with the exposures of decayed rock in railway cuts and along carriage roads, shows that this region has not escaped the decay and leveling effects of atmospheric erosion. The exposures of residual débris are not remarkable, however, as compared with typical localities in North Carolina and Virginia, for example, and seldom exceed forty or fifty feet in depth. The rock in the stream beds is quite compact, although presenting indications of considerable chemical change. This portion of South Carolina, in common with other areas in the southern Appalachians, forms an apparent exception to the rule that the residual deposits of the Atlantic States increase toward the south. As will be shown a few pages farther on, this exception is explained by the conditions of erosion which obtained in some portions of the Southern States.

In regard to the widespread decay of the crystalline rocks of South Carolina we have the testimony of M. Tuomey, whose conclusions in this connection of some forty years' standing can not be questioned, as is shown by the following quotation:

> There is scarcely anything more striking in the face of the country in this [western] part of the State than the great extent and depth to which disintegration of the rocks has proceeded. Were it not for the occasional blocks of granite that lie scattered here and there, a person whose observations were confined to the surface would scarcely suppose himself traveling over the upturned edges of a series of rocks.[1]

The quartz veins so common throughout the crystalline areas of Virginia, the Carolinas, etc., are more durable than the rocks inclosing them, and retain their integrity long after the associated schists have changed to plastic clays. Bowlders and pebbles derived from the breaking up of quartz veins cover the surface with a continuous sheet of débris over large areas, forming a residual deposit, the origin of which is revealed at a glance. The quartz itself, although opposing great resistance to disintegration, is not indestructible, as is shown by the brown, iron-stained lines that traverse it in every direction, marking the course of incipient fractures. The continual breaking of the quartz into smaller and smaller fragments produces an angular sand which everywhere forms an ingredient of the red clay soil.

When average samples of residual deposits left by the decomposition of crystalline rocks are agitated in water more or less angular fragments of quartz and feldspar, with scales of mica and fragments of other minerals, are usually obtained. This material differs with variations in the character of the parent rocks and with variations in its degree of decomposition. On examining these residual sands with the microscope, especially in cases where the decomposition is well advanced, it has been found that each grain is coated with a thin shell having a brownish or red color. Prolonged washing fails to remove this superficial coating, a fact which is well illustrated by the color of the sands deposited by the streams of Virginia and the Carolinas in the regions underlaid by crystalline rocks. Hot hydrochloric acid dissolves the coloring matter, however, and leaves the grains of quartz, feldspar, etc., with their normal tints. It has been determined from chemical analyses of a number of samples of partially decomposed crystalline rocks that the incrustation which gives the grains their characteristic color is rich in both ferric oxide and alumina, and may perhaps be best described as a ferruginous clay. It is therefore evident that the predominant red color of residual deposits is due to a coating consisting largely of ferric oxide deposited during the disintegration and decomposition of the parent rocks, around the individual grains into which the rock becomes divided in weathering.

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[1] *Report on the Geology* of South Carolina, Columbia, S. C., 1848, p. 98.

It may be remarked in passing that the residual deposits covering large portions of the crystalline areas of Virginia, the Carolinas, Georgia, and Alabama are sufficiently auriferous in many localities to be of economic importance.

The decay of the rocks in the southern Atlantic States has been observed by many travelers and has been the subject of a number of essays, as may be seen by turning to the bibliography at the end of this paper. Among the many contributions to the subject, one of the most definite and instructive is by T. Sterry Hunt,[1] who, in writing on the lithology of the southern Appalachian region, says:

> The rocks are covered often to a depth of a hundred feet or more by the undisturbed products of their own decomposition, the protoxide bases having been removed by solution from the feldspars, the hornblende, and the whole rock, with the exception of the quartzose layers, reduced to a clayey mass, still, however, showing inclined planes of stratification.

Similar testimony is furnished by W. M. Fontaine,[2] who states that—

> The depth to which decay has penetrated here [in the granites and gneisses near Richmond, Va.] is far less than in the southern and southwestern parts of the State. In the latter we find strata not specially prone to decay often decomposed and changed to a loose earth for fifty and even one hundred feet.

Descriptions of the surface decay of the rocks of the southern Appalachian region by other observers might be quoted, but enough has been presented for the purposes of this paper.

DECAY OF THE ROCKS OF THE NEWARK SYSTEM.

In the rocks of the Newark system in Virginia and North Carolina a widespread decomposition, similar to that affecting the older rocks of the same region, was observed at many localities.

The brecciated conglomerate which is found wherever the bottom of the Newark system is exposed is composed of both rolled and angular fragments of the adjacent crystalline rocks. These were compact and solid when deposited as pebbles and bowlders, but they are now often as thoroughly disintegrated and decomposed as the neighboring rocks described above. In a cut on the line of the North Carolina Railroad, 10 miles west of Wadesborough, there is a fine exposure of the basal conglomerate of the Newark. The north side of the excavation still stands as a perpendicular wall about twenty feet high, in which the variously shaped fragments composing the brecciated conglomerate are clearly distinguishable. At a little distance the rock appears almost identical with the Potomac marble, with which it agrees in geological position. On examining more closely, however, one is surprised to find that it is completely decomposed, and that, when moist, it can be cut with a pocket knife, through pebbles and matrix alike, as easily as so much potter's clay. The full depth of the alteration in this instance is not revealed, but it extends more than thirty feet below the surface without change in character. Most of the pebbles observed were formed of talcose schist and the cementing material was apparently derived from rocks of the same composition.

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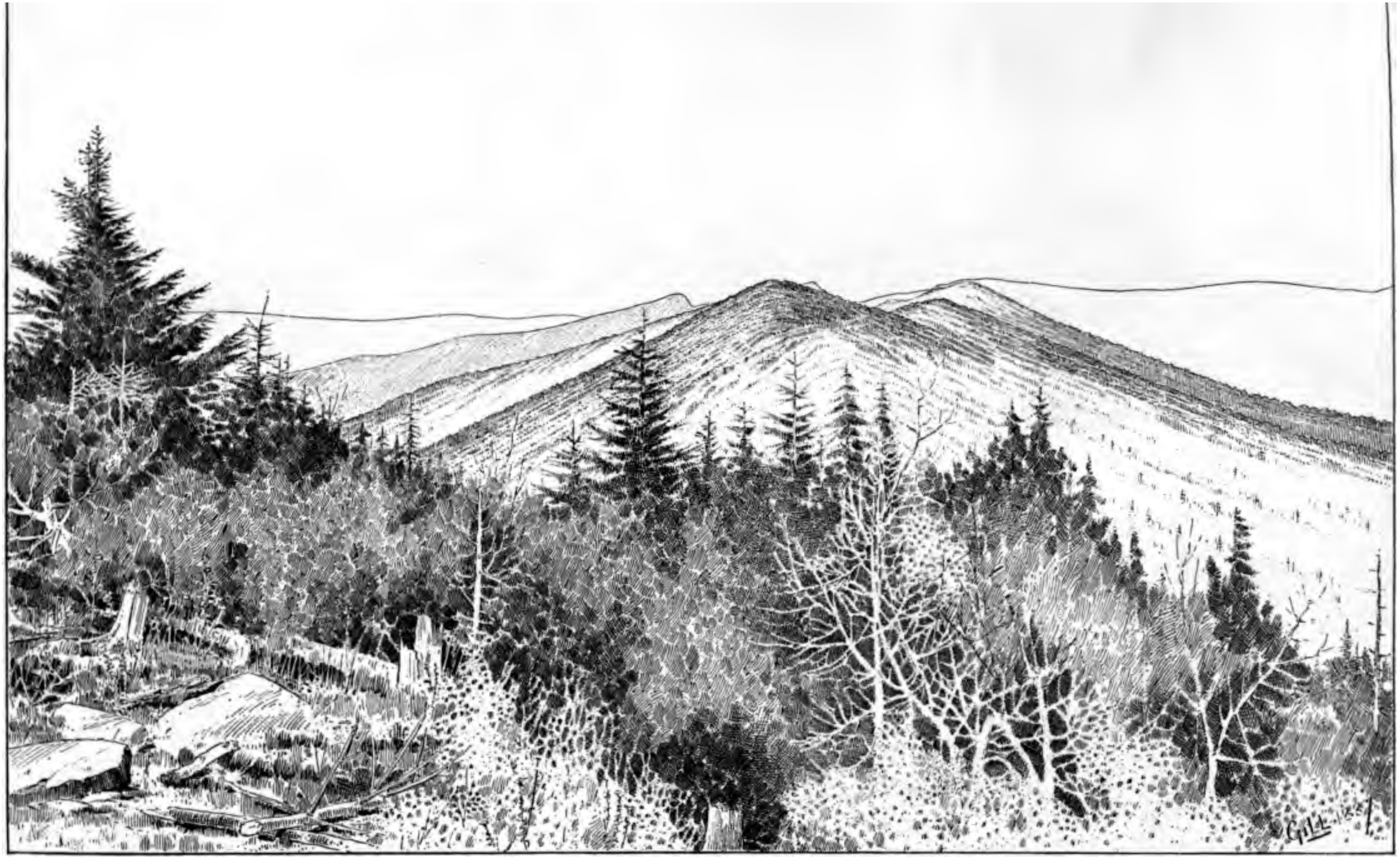
[1] Chemical and Geological Essays, 1871–1873, pp. 187, 250.

[2] Notes on the Mesozoic of Virginia, Am. Jour. Sci., 3d series, vol. 17, 1879, p. 30.

In the ordinary brown sandstones and sandy shales of the Newark system throughout Virginia and North Carolina but little subaërial decay is apparent to the unassisted eye, except in the grains of feldspar which they contain. Some of the strata in this formation are composed of plastic red clay, but whether this was deposited in its present condition or is the product of subsequent decay it is not always possible to decide.

The most remarkable example which I observed of the change that rocks undergo when long exposed to the atmosphere occurs in the trap dikes traversing the Newark system of North Carolina. These are composed of dolerite of the same character as the "traps" so abundant in New Jersey and in the Connecticut Valley, and are exceedingly numerous throughout the various Newark areas south of the Potomac. In a single section, 13 miles in length, of the Newark area which crosses Anson County, N. C., over fifty trap dikes were observed, varying from a fraction of a foot to seventy-five feet in width. It is probable that many others exist which escaped notice.

These dikes trend approximately north and south and are nearly vertical in dip. They are usually undistinguishable in the topographic relief of the region, but their presence is occasionally indicated on the surface by long lines of weathered trap bowlders. Sections of the dikes may frequently be observed in railroad cuts, and in such instances it is found that decomposition has reached to a great depth. In fresh sections forty or fifty feet deep the decomposition extends to the bottom of the exposures, without any indication of approaching its lower limit. Many dikes are completely decomposed throughout, and the originally hard, tough, bluish dolerite, which would ring under the hammer, has been transformed into a yellowish, clay like



VIEW OF MOUNT MITCHELL, NORTH CAROLINA, LOOKING NORTH ALONG THE CREST OF THE BLACK MOUNTAINS.

mass that can be molded in the fingers and cut like putty. In some cases, especially in the larger dikes, the decomposition is only partial, and the loose rotten mass contains rounded bowlders in process of disintegration, in the center of which the rock still exhibits its original characteristics. These bowlders usually occupy the center of a dike, as seen in vertical section, but at times there are two or more vertical bands of them distributed through the decomposing rock. The sides of the fissures through which the trap ascended are hardened or metamorphosed at some localities by the contact of the igneous rock, and thus rendered unusually durable. In such instances the trap is often completely decomposed, while the walls of hardened sandstone exhibit no sign of disintegration.

It is a noticeable fact that wells sunk in or near trap dikes in the Newark areas of North Carolina contain unusually "hard" water, which is frequently brackish. It may be that the saline matter in these wells was derived from salts impregnating the surrounding sedimentary rocks, but they must also receive mineral matter from the decomposing igneous rocks.

In speaking of the trap dikes in South Carolina, which belong to the same great system as those just considered, M. Tuomey remarks:[1]

> Both the trap and other rocks with which it is associated are so much disintegrated that it is impossible to observe the form presented by the dikes at the surface. I have not met with a single instance where this rock presented anything like an escarpment, although the manner in which it penetrates the rocks through which the dikes pass may be observed at many places, in ravines and such localities. On the surface the dikes are readily traced by the long lines of black or dark green and ferruginous spherical masses of trap scattered along in the direction of the dikes, often for miles in extent.

A chemical examination of decomposed trap from a dike near Wadesborough, N. C., shows that it is essentially a kaolin containing about seventeen per cent. of ferric oxide. An approximately complete analysis of this material by T. M. Chatard is given below, together with the average composition of eight samples of unaltered dolerite from New Jersey and the Connecticut Valley, as determined by G. W. Hawes.[2] The trap rocks are, in general, so nearly identical throughout the Newark system that we may consider this average as representing very closely the composition of the rock from which the residual clay described above was derived. It will be seen by the comparison that a large part of the silica, as well as of the more soluble portions of the original rock, has disappeared from the residual deposit, while the relatively insoluble alumina and ferric oxide have greatly increased their percentages.

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[1] Report on the Geology of South Carolina, Columbia, S. C., 1848, pp. 65, 66.

[2] Am. Jour. Sci., 3d series, vol. 9, 1875, pp. 185-192 [the analyses used are on pp. 186, 187, 189].

Analyses of dolerite.

Constituents.	Average composition of unaltered dolerite.	Decomposed dolerite from Wadesborough, N. C.
Silica (SiO_2)	52.50	39.55
Alumina (Al_2O_3)	14.15	28.76
Ferrous oxide (FeO)	9.24	....
Ferric oxide (Fe_2O_3)	1.96	16.80
Manganous oxide (MnO)	0.45	Trace.
Lime (CaO)	10.03	0.37
Magnesia (MgO)	7.48	0.59
Chromic oxide (Cr_2O_3)	....	Trace.
Soda (Na_2O)	2.30	Trace.
Potash (K_2O)	0.69	Trace.
Phosphoric acid (P_2O_5)	0.14	0.10
Titanic acid (TiO_2)	....	0.64
Water (by ignition) (H_2O)	0.92	13.26
Total	99.86	100.07

In following the rocks of the Newark system south from Pennsylvania, through Maryland, Virginia, and the Carolinas, one finds the trap dikes exhibiting greater and greater evidences of decomposition. Thus, as in the case of the Archæan granites and schists and the Newark conglomerates, the decay of the eruptive rocks increases towards the south.

DECAY OF ROCKS IN THE SOUTHERN APPALACHIANS.

Subaërial decay is marked among the mountains of western North Carolina and eastern Tennessee, where the material filling the valleys, as in the lowlands to the eastward, is usually a red clay, in which angular fragments of quartz, feldspar, and mica are intermingled. All the stages in the formation of this material from the underlying schists and associated rocks may be observed at many localities. The same is also true of large portions of the mountainous region of Georgia and Alabama. In the area underlaid by Ocoee schists, however, which borders the more intensely metamorphosed rocks of the southern Appalachians on the west, transportation is being carried on so rapidly that comparatively little residual material remains. The reason of the more energetic action of the streams in this region is to be found in the fact that the limestone rocks bordering the Ocoee formation on the west are much more easily removed than the less soluble slates and schists of the metamorphic area; hence the latter stand in relief and impart a high grade to the stream channels which lead from them. The streams are consequently rapid, and the surrounding slopes are in many places stripped of their residual deposits.

Throughout the southern Appalachians we find abundant illustration of the rounded summits and flowing outlines characteristic of a land that has been long subjected to decay, and in which decomposition and disintegration in general exceed transportation. Even in the most elevated portions of this range, however, the scenery is subdued and pleasingly picturesque, partaking rather of the beauty of hills overlooking pastoral valleys than of the rugged grandeur of mountains such as the Sierra Nevada and the Alps. To the geologist these differences appear to be wholly due to variations in the balance between disintegration and transportation. The mountains of the southern Atlantic States have a softness of outline and a delicacy of tint peculiarly their own, which depend largely on the luxuriance of the vegetation with which they are clothed, and on the vapory atmosphere with which they are surrounded. The charm of their beauty can not be shown in ordinary illustrations, but must be seen and felt to be understood. The flowing outlines of the hills and something of the atmospheric effects of the climate of the South may be gathered from the accompanying picture of the New Found Mountains, as seen from near Asheville, N. C.

Another convenient locality for studying the effects of atmospheric forces on crystalline rocks is furnished by the street excavations and suburban improvements of Atlanta, Ga. In every direction about that city the evidence of deep rock decay is to be seen, and the landscape presents the subdued outlines characteristic of "topographic old age."

In describing the formation of soils by the decay of the metamorphic rocks of eastern Alabama (and the observation would apply equally well to large areas in Georgia), E. A. Smith observes:[1]

> In some parts the strata have undergone complete disintegration in place, and have been converted into great masses of stratified clays, interlaminated with seams of quartz, which, gradually broken down, cover the ground with their angular fragments. The depth to which this decay reaches depends on the nature of the rock and its position, and in many instances even twenty or thirty feet below the surface the rock is still decomposed.

In the region mentioned in the last paragraph two varieties of soil, termed red and gray, are recognized by the author quoted:

> The soil of the red lands is derived from the decomposed hornblendic gneisses and slates, which in many places, where exposed in washes or gullies, are seen to be mere stratified clays, containing fragments, more or less angular, of the quartz veins or seams which are nearly always interbedded with the other rocks of this region. The top stratum of this soil, from two to three inches in depth, has often a dark chocolate-brown color, but below it becomes a bright red, and at varying depths, from ten to fifteen feet, becomes a yellowish hard clay. Where the freshly decomposed rocks are seen the color is yellowish rather than red, the latter color being darker and more in-

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[1] Geol. Survey Alabama, Rept. for 1881 and 1882, p. 184.

tense apparently the further removed the soil is from its original position and the more it is affected by the decay of the vegetable matter.

The gray soils result from the disintegration of gneisses and mica slates, which contain comparatively little or no hornblende or other iron-bearing minerals. They are commonly somewhat sandy, usually light-colored, gray to dark gray, sometimes nearly black, with very often, however, a decidedly reddish color, similar to that of the hornblendic soils above described. Fragments of the partially decayed gneiss of a light-gray color often lie embedded in reddish and even red clays or clayey sands.[1]

A number of analyses of the soils of the metamorphic region of Alabama, of interest to the student of rock decay, are given in the report just cited.

DECAY OF ROCKS IN THE GREAT APPALACHIAN VALLEY.

In traversing the Great Appalachian Valley[2] from Pennsylvania to Alabama, an increase in the extent and depth of the residual deposits toward the south was again observed.

This great valley owes its formation primarily to an upheaval, which brought the rocks within the reach of denuding agencies. The present topographic diversity, however, is not due to an elevation of the borders of the valley, but to the denudation of its bottom. The removal of rocks has been carried on, as usual, by the action of running water, but its work has been performed largely by chemical solution. That this process is still continuing is shown by the thousands of "sink holes" and by numerous valleys without surface drainage, to be seen in the limestone areas from Pennsylvania to Alabama. It is also indicated by hundreds of fine springs, and by numerous caverns, of which Luray is a type, which owe their existence to subterranean solution.

Throughout the entire extent of the valley thousands of feet of strata, principally of limestone, have been removed. In the Coosa Valley, Alabama, which is a portion of the Great Appalachian Valley, the minimum thickness of strata carried away since the Carboniferous period, as determined by careful measurements, is not less than eight or nine thousand feet. The maximum denudation, of which no accurate determination has been made, may largely exceed this.

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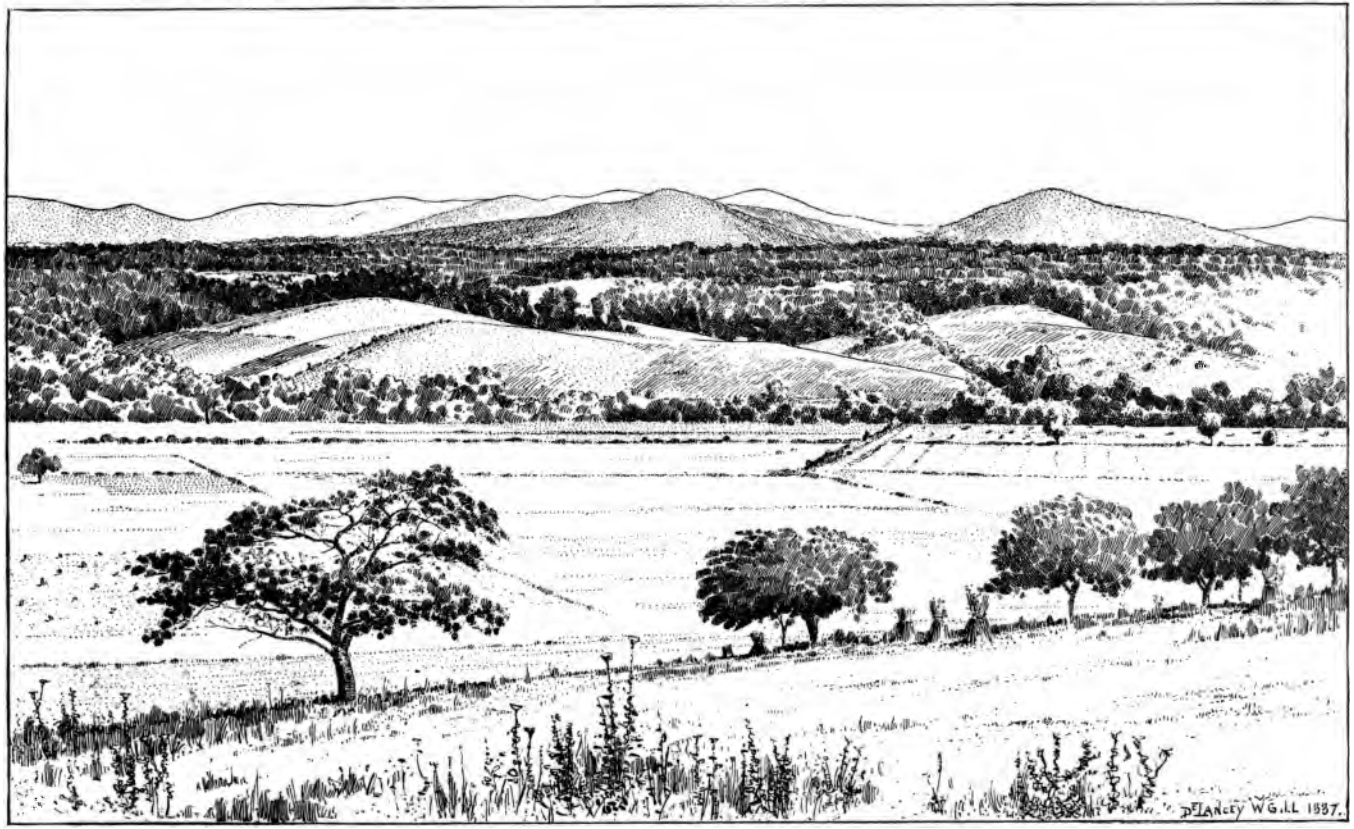
[1] Geol. Survey Alabama, Report for 1881 and 1882, pp. 183–187.

[2] The valley referred to occupies for the most part a well-defined position between the Appalachian Mountains on the east and a great but somewhat indefinitely defined table-land—known as the Cumberland, Alleghany, and Catskill plateau—on the west. It crosses the prevailing corrugations of the Appalachians somewhat obliquely, its prevailing trend being nearly northeast and southwest, and in Pennsylvania is to the east of the Alleghanies. It has many local names; in Alabama it is occupied principally by the Coosa River, and is known as the Coosa Valley; farther north it is the valley of East Tennessee and the valley of Virginia; in Maryland and Pennsylvania it is the Cumberland Valley; in Pennsylvania it becomes the Lebanon and Kittatinny Valleys; in New Jersey and New York it is drained by the Walkill. The upper portion of the Hudson River Valley and the depression occupied by Lake Champlain are portions of the northern extension of the same topographic feature.


DeLancey W. Gill 1887.

NEW FOUND MOUNTAINS LOOKING SOUTHWEST FROM ASHEVILLE NORTH CAROLINA.

The predominant rock of the Great Appalachian Valley is Paleozoic limestone. Throughout large areas, especially in Alabama and Georgia, this rock is highly charged with magnesia and silica and becomes a cherty dolomite. It is in regions underlaid by rocks of this character that the most abundant accumulations of residual deposits occur. The chert, being slow to decay, accumulates at the surface as the inclosing limestone dissolves away, and, together with the residual portion of the limestone, forms rounded hills and gentle ridges in which rock in place is seldom seen owing to the depth of the subaërial deposits. Over large areas in Wills and Coosa valleys, Alabama, residual deposits of this character have in general a minimum thickness of not less than a hundred feet. Their maximum thickness is probably two or three times as great. In regions where the limestone is less silicious the residual deposits are more homogeneous and usually consist throughout of red clay, frequently rich in concretionary iron ore.

The red earth, containing angular fragments of chert which have resulted from the decay of magnesian limestone (Knox dolomite) in the southern part of the Great Appalachian Valley, is very similar both in character and mode of origin to the red earth charged with flints which forms the surface over portions of the Chalk formation in the south of England, as described by W. Whitaker.[1]

The chert, or "flint," which occurs in great quantities in the Silurian and Carboniferous rock of Tennessee and Alabama, although exceedingly hard and giving every indication of durability when fresh, crumbles to a fine white powder, bearing no resemblance to the original rock, when long exposed to the atmosphere. This change has been observed to extend to the depth of two or three feet from the surface of a bed of chert, which at a greater depth was compact and hard. The change from altered to unaltered chert is abrupt, and hand specimens may easily be collected in which one-half is a compact, bluish chert, fit for gun flints, and the other half a powdery, amorphous mass that crumbles between the fingers. The fact that the entire specimen in such an instance was originally homogeneous is shown by the concentric lines and bands of various tints that traverse both the solid and the friable portions without interruption.

The soil formed by the decay of the more calcareous portion of the magnesian limestone (Knox dolomite) of Alabama is thus described by Eugene A. Smith:[2]

> A clayey loam of light yellowish to orange-red colors and of varying thickness, the average being perhaps 1½ feet. The subsoil is usually heavier, being a rather stiff clay or clayey loam of a red or yellow color. Both soil and subsoil are often filled with lumps of limonite or brown iron ore. Beneath the subsoil, at varying depths, lies the dolomite, or limestone. There is a great variety in the color of the top soil, between a

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[1] Mem. Geol. Survey Great Britain: The geology of Middlesex, Hertfordshire, etc. London, 1864, pp. 63–66.

[2] Geol. Survey Alabama, Rept. for 1881 and 1882, p. 200.

very light yellow, almost gray, and a deep red and brown; but the subsoil is commonly a yellow or red clay, and it is not unusual to find these soils and subsoils, especially those of a light color, filled with angular fragments of chert.

Portions of the Silurian rocks of Alabama, readily recognized as limestones when unweathered, are easily mistaken for sandstones and shales when only their weathered outcrops can be seen. The Clinton ore, or "fossil ore," interbedded with strata of shale and sandstone, forms one of the most characteristic beds in the Upper Silurian rocks of Tennessee and Alabama. In the mines of Gadsden and of Atalla, Ala., where Clinton ore is worked, the strata are highly inclined (a dip of 70° to 80° to the southeast prevailing) and well exposed for study. The outcrops of the beds are of soft, porous, highly fossiliferous ore, which has a deep brownish red color and is easily worked and easily smelted. The ore at Atalla retains this character to the depth of about two hundred and fifty feet, measured down the slope, and then changes to a hard, compact, ferruginous limestone, rich in fossils.[1] The marked difference in the character of the ore in the upper portions of the mines as compared with that from the lower portions is due entirely to weathering. This is shown by the general appearance of the ore at various horizons and by its chemical composition. Two typical samples of the ore, selected by me—one from near the surface, representing the ordinary character of the soft ore, and the other from a depth of two hundred and fifty feet, representing the hard ore, but not the most calcareous variety—gave on analysis the following percentages of iron, lime, and carbonic acid, after drying at 105° Centigrade:

Analyses of Clinton iron ore. By R. B. Riggs.

Constituents.	Surface sample.	Sample from 250 feet below surface.
Iron (Fe)	57.52	7.75
Lime (CaO)	1.38	47.64
Carbonic acid (CO_2)	0.30	34.90

The increase of lime in the Clinton ore of the Great Appalachian Valley when followed below the surface is well shown in the following table, compiled from analyses of ore mined near Birmingham, Ala., which I copy from a paper by John B. Porter:[2]

The ore is 13 feet thick and highly tilted, with an outcrop which has been located for many miles. At the time of the analysis the mine was 130 feet deep on the ore, and the following figures give the percentage of carbonate of lime for each 10 feet descent:

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[1] A similar change in fossil ore has been noted by T. H. Dewees, in Pennsylvania; Second Geol. Survey Pennsylvania, Report F, 1878, p. xlvi.

[2] "The iron ores and coals of Alabama, Georgia, and Tennessee." Trans. Am. Inst. Mining Engineers, vol. 15, p. 189.

Percentage of lime in Clinton iron ore.

Surface	Trace.	70 feet below surface	25.61
10 feet below surface	Trace.	80 feet below surface	29.92
20 feet below surface	Trace.	90 feet below surface	29.89
30 feet below surface	Trace.	100 feet below surface	23.37
40 feet below surface	21.06	110 feet below surface	28.82
50 feet below surface	23.90	120 feet below surface	21.32
60 feet below surface	37.01	130 feet below surface	30.55

At Atalla the change from "soft ore" to ferruginous limestone, or "hard ore," takes place at about the present level of stream drainage. At this horizon the stratum increases from two feet and a half to three feet in thickness. This increase in thickness below the level of drainage indicates that the removal of the calcareous portion of the ferruginous strata has allowed the bed to be compressed. As the unweathered ore is of doubtful economic value, owing to its high percentage of lime and the difficulty of mining, exaggerated estimates of the importance of the Clinton ore deposits of the South are to be guarded against.

The Carboniferous rocks of eastern Alabama at some localities occur next above the Clinton, but are usually separated from it by a stratum of highly bituminous shale and sandstone, about thirty feet thick. In these Carboniferous rocks there are heavy layers of highly silicious limestone, abundantly charged with crinoidal remains. In its unweathered condition, which is seldom observed, this is a dark, heavy, siliceous rock, in which the fossils are quite obscure. On the surface, and usually to the depth of fifty or sixty feet, this rock appears as a porous chert, which is traversed in every direction by cavities left by the solution of fossils, principally the stems of crinoids. A greater contrast than is presented by the massive black limestone as it appears in its unweathered condition and the light-colored, slag-like chert of the weathered outcrops could scarcely be imagined. The débris of this peculiar siliceous limestone is found in most of the "red ore ridges" of Tennessee and Alabama, and when its geologic relations are known to the miner it furnishes an important aid in tracing the deposits of Clinton ore, with which its association is quite constant.

Many other illustrations of the character and of the extent of the weathering which has affected the rocks in the southern part of the Great Appalachian Valley, with reference especially to the genesis of limonite and manganese deposits, might be enumerated; but enough facts have probably been presented for the purpose in hand.

Residual clays of the same character and origin as those which impart their characteristic color to great areas in Alabama and Tennessee also occur in that portion of the Great Appalachian Valley which lies in Virginia, Maryland, and Pennsylvania. In the northern portion of the valley, however, especially north of the James, the clays are not so continuous or of so great a thickness as farther south.

Throughout the valley of the Shenandoah and in the region drained by the James, New River, etc., in Virginia, the surface of the country is covered to a depth sometimes exceeding fifty feet with a red clay which has resulted almost entirely from the decay of limestone. This is a residual deposit that accumulated at the surface as the limestone in which it once formed an impurity was slowly dissolved away. It is evidently the product of a very long period of concentration, as the insoluble portion of the limestone in this region constitutes but a very small part of its weight.

In the following analysis the composition of a sample of light gray Trenton limestone from Lexington, Va., is given, together with the analysis of a characteristic sample of the superficial red clay of the same region, which was left after the removal of the more soluble portions of the limestone.

Analyses of Trenton limestone and of the residue left by its decay. By R. B. Riggs.

Constituents.	Unaltered limestone.	Residual clay.
Silica (SiO_2)	0.44	43.07
Alumina (Al_2O_3)	0.42	25.07
Ferric oxide (Fe_2O_3)		15.16
Lime (CaO)	54.77	0.63
Magnesia (MgO)	Trace.	0.03
Potash (K_2O)	Not det'd.	2.50
Soda (Na_2O)	Not det'd.	1.20
Carbonic acid (CO_2)	42.72	....
Water (H_2O)	1.08	12.98
Total	99.43	100.64

An analysis of magnesian limestone (Knox dolomite) from Morrisville, Ala., and of the residual clay left by its decomposition, is here inserted, to illustrate still further the chemical changes which occur during the decay of calcareous rocks. The original rock in this instance was a grayish-white dolomite, typical of its class over a large area in the southern part of the Great Appalachian Valley, while the clay left by its decay is a fair sample of the red soil of the South.

Analyses of dolomite and of residual clay left by its decay. By W. F. Hillebrand.

Constituents	Unaltered dolomite.	Residual clay
Silica (SiO$_2$)	3.24	55.42
Alumina (Al$_2$O$_3$)	0.17	*22.17
Ferric oxide (Fe$_2$O$_3$)	0.17	8.30
Ferrous oxide (FeO)	0.06	Trace.
Lime (CaO)	29.58	0.15
Magnesia (MgO)	20.84	1.45
Potash (K$_2$O)	....	2.82
Soda (Na$_2$O)	....	0.17
Carbonic acid (CO$_2$)	45.54	....
Water (H$_2$O)	0.30	†9.36
Total	99.90	99.84

* With TiO$_2$ and P$_2$O$_5$. † 2.10 at 100° C.

These investigations indicate that approximately from one to four per cent. of ordinary light-colored limestones, depending mainly on the amount of silica and alumina they contain, remains behind and contributes to the formation of residual clays when subaërial decay takes place. These analyses, however, are somewhat unsatisfactory in this connection, as only a small quantity was used in each instance, and no attempt was made to determine the minute portions of various elements which might reasonably be expected to be present.

The red earth of the southern portion of the Great Appalachian Valley is apparently identical, both in composition and in the method of its accumulation, with the "terra rossa" of southern Europe, the "laterite" of India, and the "red earth" of Bermuda, each of which will be noticed further on.

The red clay so frequently found in caves, especially in the limestone regions of the Southern States, and known as "cave earth," is another occurrence of the residual deposits resulting from the subaërial decay of rocks, and at times has considerable interest.

Although quantitative measurements of the extent and thickness of residual deposits of the Great Appalachian Valley have not been made, yet qualitative observations are sufficient to show that, like the similar deposits covering the crystalline and Newark areas east of the Blue Ridge, they are far more abundant in the South than in the North, as has already been stated, and increase gradually as one travels from north to south.

A comparison of the southern Appalachian region with the driftless area of the upper Mississippi Valley, as described by T. C. Chamberlin and R. D. Salisbury,[1] shows that rock decay is far more advanced in the former region than in the latter. The average of one thousand eight hundred measurements of the depth of residual deposits over the driftless area of Wisconsin as given in the report referred to above, is 7.08 feet, the maximum, which was possibly in an enlarged fissure, being 70 feet. A general inspection of the southern Appalachian region is enough to assure one that residual deposits are there at least ten or fifteen times as thick as the estimated average thickness of the similar deposits in Wisconsin, etc. The driftless area described by Chamberlin and Salisbury is characterized by outstanding towers of castle-like masses of rock, frequently spoken of as "erosion columns," that have been left in bold relief by the removal of the surrounding strata. In the Southern States no such records of the former extent of particular formations are to be found. Their existence, except in immediate proximity to cliffs, is precluded by the fact that the rate of decay exceeds the rate of transportation.

The general rounded character and soft, flowing outlines of a limestone country that has long been exposed to atmospheric decay is illustrated by Plate III, which represents the characteristic scenery between Lexington and Natural Bridge, Va. The elevated table-land in the background of the picture is House Mountain, which overlooks Lexington.

The increase of residual deposits toward the south in the Appalachian region is a geologic feature of interest, and one that demands explanation. A discussion of this question will be postponed for a few pages, however, in order to present something of the effects of subaërial decay in other regions, and to state the nature of the chemical changes which take place in rocks when exposed to atmospheric influences.

ABSENCE OF DECAYED ROCKS IN THE FAR WEST.

Nothing comparable with the extensive disintegration and decay of the rocks forming the southern portion of the Appalachian Mountains has been observed by me during somewhat extended journeys through other portions of the United States. In the Northeastern States the records of such decay are mostly obscured and obliterated by glacial deposits. West of the Mississippi, in New Mexico, Colorado, Idaho, Utah, Nevada, Oregon, and California, only secondary glaciers originating from local centers existed during the glacial epoch. The rocks in large portions of this region have presumably been subjected to subaërial influences fully as long as in the South Atlantic States, but no marked evidences of general decay are to be seen. In the mountains of the Far West, which, as nearly as I can judge, may be fairly compared with the more elevated portions

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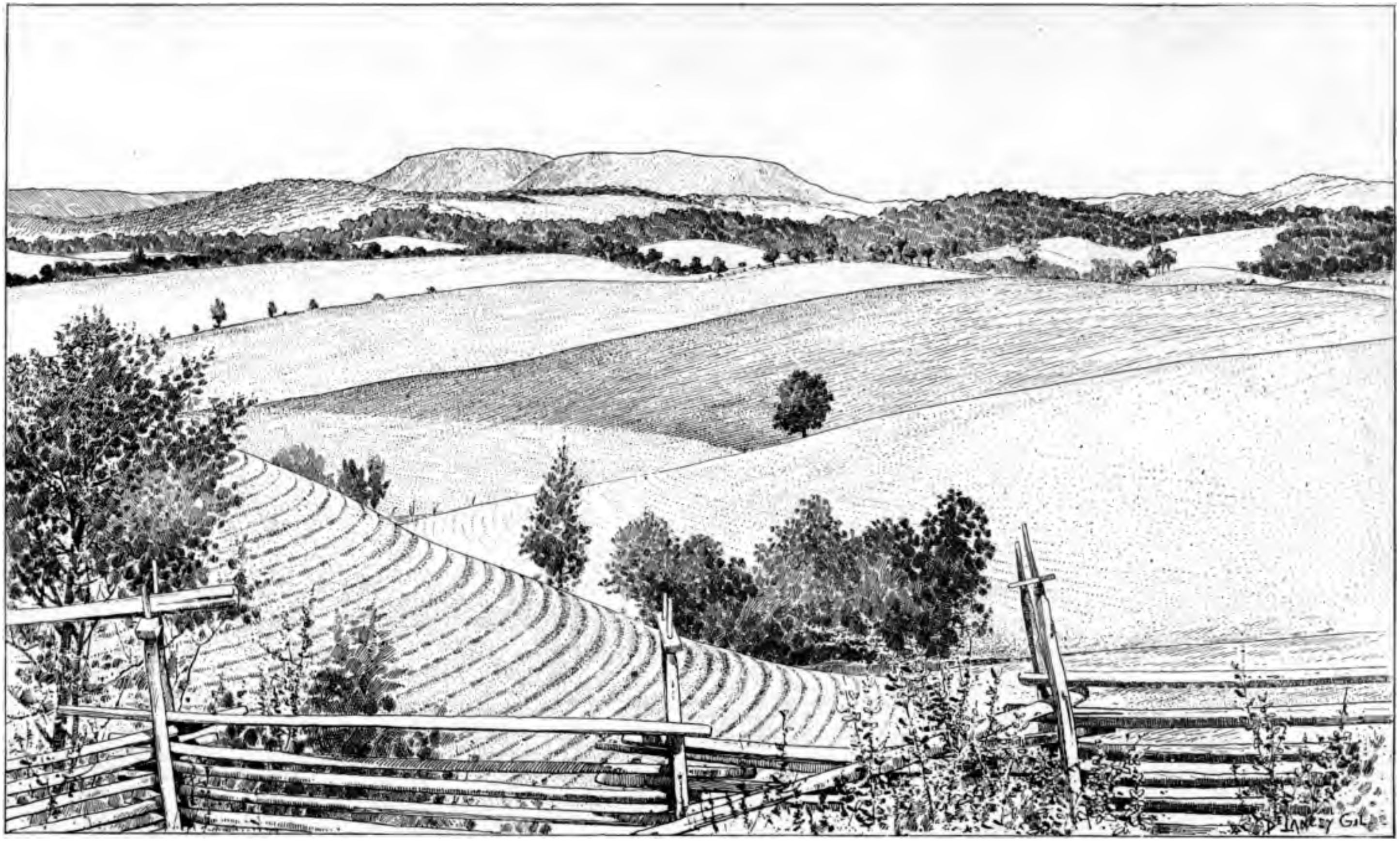
[1] U. S. Geol. Survey, Sixth Ann. Rept., p. 205.



VIEW OF FIELDS OF RESIDUAL CLAY NEAR NATURAL BRIDGE, VIRGINIA, LOOKING NORTH; HOUSE MOUNTAIN IN THE BACKGROUND.

of the southern Appalachians, so far as the conditions of transportation are concerned, the evidences of subaërial decay are not strongly pronounced, and, in fact, are usually absent. It is a matter of observation that the soil formed by the decay of a great variety of rocks is a red clay, which, in the more advanced stages of decomposition, is strikingly similar, both in appearance and in constituents, the world over. In the arid portion of the Far West soils of this character are wanting, and the prevailing tone of the landscape, so far as it is influenced by the color of the soil, or by the color of subaërial deposits generally, is subdued and unobtrusive, being usually gray, or light yellow brown. The brilliant coloring on the mountains and the gorgeous hues revealed in the cañons of this region are not due to products of decay, but to the inherent tints of the rocks. The marked contrast that exists in the colors of the superficial deposits in the South Atlantic and South Pacific borders of the United States can be illustrated in fancy by comparing the ashen tints of the Mojave desert with the brilliant reds and yellows that would be revealed could the vegetation be removed from Virginia and her sister States.

In considering the absence of red soils in the Far West the arid region alone is referred to. There are areas of considerable extent on the west slopes of the Sierra Nevada where deep rock decay has taken place and where the red color of the soil reminds one of the southern Appalachians. In this region the present rain-fall is about forty-five inches annually, and the country is clothed with vegetation. The climatic conditions thus approximate to those prevailing in the Middle Atlantic States, and the decay observed in the rocks, including schists, slates, and limestones, is what one would expect from the climatic environment. The west slope of the Sierra Nevada in central California is a plane inclined at a gentle angle, in which the streams have sunken their channels a thousand feet or more. The cañons are narrow, with precipitous sides, and are floored with rock that has suffered but little decay. These conditions indicate that the region referred to underwent a long period of disintegration before the plain was tilted so as to allow the streams to excavate their present channels. That the stream channels are of more recent origin than the principal part of the rock decay is shown by the occurrence of residual clays, sometimes fifty or seventy-five feet thick, on the hill-tops. These conditions are well illustrated in the hydraulic mines on Feather River, and may be studied to advantage at Colfax, Cal.

There are probably other areas in the Far West where rock decay is as marked as on the west slope of the Sierra Nevada, but they have not come under my notice. What the effects of the heavy rain-fall, and consequently dense forests, of the northern part of the Pacific Slope may be on the decay of rocks remains to be observed.

SUBAËRIAL DECAY IN OTHER COUNTRIES.

The studies of previous observers have shown that subaërial decay is a marked feature of the surface rocks in many other countries.

The extent to which rock decay has reached in portions of Central America is indicated by the following quotation descriptive of portions of Nicaragua, by Thomas Belt:[1]

> The decomposition of the dolerites is very great, and extends from the top of the hills to a depth (as proved in the mines) of at least two hundred feet. Next the surface they are often as soft as alluvial clay, and may be cut with a spade. This decomposition of the rocks near the surface prevails in many parts of tropical America, and is principally, if not always, confined to the forest regions. It has been ascribed, and probably with reason, to the percolation through the rocks of rain water charged with a little acid from the decomposing vegetation. If this be so, the great depth to which it has reached tells of the immense antiquity of the forests.

On the island of Curaçao, off the coast of Venezuela, as described by W. M. Gabb,[2] the rock is limestone and the soil is scanty. "There is no vegetable mold, and the earth is red, the same characteristic 'red earth' or clay as that found in Jamaica, Santo Domingo, the Bahamas, etc. The climate and vegetation are very similar to the rainless parts of Santo Domingo."

The observations of Agassiz, Liais, and Hartt indicate that the rocks over a large portion of Brazil have also been profoundly affected by the chemical action of the atmosphere and of atmospheric waters.[3]

In southeastern Europe a superficial deposit of red clay, or "terra rossa," resulting principally from the subaërial decay of limestone, occurs throughout the Istrian Peninsula, Dalmatia, Greece, etc. This deposit has been described and discussed to some extent by Stoppani, Fuchs, Neumayr, and others.

In the Spanish Peninsula the products of subaërial decay are to be seen on every hand; especially in the region southward of Madrid, where the landscape frequently calls to mind the characteristic features of central Virginia.

In southern Asia the deposit termed "laterite," formed by the subaërial decay of basalt, gneiss, granite, etc., is of wide geographic extent, and is one of the most interesting features in the surface geology of the country. Its thickness on the basaltic plateaus of western India sometimes reaches two hundred feet. Near Madras it imparts its characteristic color to the Red Hills. When not exposed directly to the action of the atmosphere, it is soft and may be easily cut into blocks with a knife; on exposure to the air these soon harden sufficiently to form a durable building stone. This formation is so widely spread and so characteristic that it has attracted the attention of nearly all who have studied the geology of India. The observations concerning it have been summarized by Medlicott and Blanford in their Manual of the Geology of India.

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[1] The Naturalist in Nicaragua, London, 1888, 12mo., p. 86.

[2] Notes on the Island of Curaçao, Am. Jour. Sci., 3d series, vol. 5, 1873, p. 383.

[3] For references consult bibliographic list at the end of this paper.

The subaërial decomposition of basalt has been observed by J. D. Dana in Australia, Tahiti, and Tierra del Fuego; and similar alterations of other rocks have been noted in New Zealand and in China.

Perhaps the most instructive instance of the origin of a residuary deposit rich in iron from a formation that is not iron-stained is furnished by the "red earth" of Bermuda. The islands are composed, probably throughout, of coral limestone and are remote from any region that could contribute foreign material in any considerable quantity. The soil is a red clay which has been left as the more soluble portions of the limestone were dissolved away. In composition it closely resembles the similar red soils of Virginia and of many other regions, as is shown by the following analyses which we copy from C. Wyville Thomson's book, The Atlantic:[1]

Analyses of red soil and of coral from Bermuda.

Constituents.	Red soil.	Coral from which the red soil was derived.
Hygroscopic water (H_2O)	18.265	0.328
Silica (sand) (SiO_2)	45.156	0.052
Sesquioxide of iron (Fe_2O_3)	13.898	0.540
Alumina (Al_2O_3)	15.473	
Lime (CaO)	3.948	54.496
Carbonic acid (CO_2)	2.533	44.521
Sulphuric acid (SO_4)	Trace	0.214
Chlorine (Cl)	Trace	0.021
Magnesia (MgO)	0.539	1.751
Potash (K_2O)	0.133	0.066
Soda (Na_2O)	0.007	0.252
Phosphoric acid (estimated in nitric acid solution) (HPO_4)	0.704	0.080
Total	100.656	102.321

An earth of similar character and origin occurs in the Bahamas, where the underlying rock is also coral limestone.

Superficial deposits resulting from secular decay have been described by various geologists in this country, as is indicated by the accompanying bibliographic list; but these observations are not inserted here at length, as they have already been assembled by T. Sterry Hunt in his essay on the decay of rocks.[1]

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[1] Vol. 1, pp. 325, 327. These analyses have been recalculated and organic matter left out. Other analyses of the soils of Bermuda may be found in J. H. Lefroy's essay on the botany of Bermuda, Bull. U. S. Nat. Mus. No. 25.

CONDITIONS FAVORING THE DECAY OF ROCKS.

The extent below the surface to which rock decay extends indicates, in addition to the evidence of chemical changes, that such alterations have been produced by percolating waters and not by changes of temperature or any other cause with which we are familiar. The strain produced by changes of temperature and the freezing of water in the interstices of rocks, although of very great importance in assisting in their alteration, is confined to the superficial portions of outcrops.

The conditions, therefore, which facilitate the passage of percolating waters, especially of waters charged with organic acids through rocks, will favor decay. As is shown below, this process is regulated by climate.

In desert regions a hard, superficial crust is frequently formed on rock surfaces, probably by the deposition of mineral matter brought in solution from the inner portions of the rocks and precipitated as evaporation takes place. The "desert varnish," so common in arid regions, appears also to be of this nature. When the climate is sufficiently dry to admit of the formation of incrustations of this character, atmospheric influences are evidently conservative rather than destructive.

In high latitudes very little evidence of subaërial decay has been noted, but this may be due to lack of observation, to the recent existence of glaciers, or perhaps to the prevalence of abundant means of transportation.

I may remark from observation that in the Kerguelen and Crozet Islands, in the South Indian Ocean, where a cold, humid climate prevails, and where not only forests but arborescent growths of every description are wanting, there is but little soil, and nothing approaching terra rossa is to be seen. These islands are formed, probably throughout, of dark basaltic rocks, rich in iron, which under more favorable conditions would yield a deep layer of ferruginous soil. Contrast with the Kerguelen Islands others of similar origin in the tropics, as the Samoan Islands, for example. On Kerguelen the highest vegetation is a bitter cabbage which grows mostly in sheltered places along the coast, where it is surrounded with matted ferns and tussocks of moss. The landscape, even on the exceptional days of sunshine, is dark, silent, and gloomy. Among navigators this island is called, not unjustly, the "Land of Desolation." In the Samoan Islands the rank luxuriance of tropical vegetation imparts to the land when seen from the ocean the deep tint of malachite. Wherever the bare earth appears it gleams forth through the overshadowing boughs with a brilliancy that is enhanced by contrast and gives a dash of Pompeian red to the picture of tropical beauty. The soil is deep and rich, and, as in Bermuda, must have been derived entirely from the decay of the rocks forming the islands, which in this case, however, are basaltic, and agree in many ways with the rocks forming the Kerguelen Islands.

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[1] Am. Jour. Sci., 3d series, vol. 26, 1883, pp. 190–213. Republished in Mineral Physiology and Physiography, Boston, 1886, pp. 246–278.

The contrast between the present condition of the Kerguelen Islands and that of the Samoan Islands has resulted from differences in climatic conditions. This conclusion would have to be modified, perhaps, should it be found that the former had recently been glaciated. There are abundant observations to show, however, that, in general, islands below latitude 50° south, where winter is almost continuous, are desolate, uninhabitable wilds, and that forty degrees nearer the equator, where perpetual summer reigns, lands formed of nearly identical rock have suffered deep decay and are covered with a rich ferruginous soil, which supports a varied and luxuriant tropical flora.

These observations concur with the conclusions of G. P. Wall and J. G. Sawkins concerning the formations of the soil of Trinidad, from which the following is copied:[1]

> When the temperature is low, as in northern climates, the operation [of rock disintegration] (notwithstanding the action of frost) progresses very slowly. The soil is of the thinnest description, and even a bare surface of the original rock is frequently exposed; but, under this latitude [ten degrees north] and with the excessive moisture of this climate, it may be doubted whether any but the hardest quartz can entirely escape degradation, while in most cases the resulting soil will be of great depth.

On considering the geographical distribution of residual deposits, together with other facts bearing on the question, it seems safe to conclude that, in general, subaërial decay is more rapid in warm than in cold regions, and is far greater in humid than in arid climates. The most favorable conditions occur in warm, moist climates.

The intimate relation between climatic conditions and rock decay here stated might perhaps be considered as simply a coincidence, and not of the nature of cause and effect. The writer is not prepared to discuss in all their details the chemical processes which have transformed the superficial portions of the earth's crust and rendered it suitable for the formation of soil and the growth of vegetation, but the effects of climate in this connection may be designated in a general way.

Among the first conditions influencing rock decay is temperature. Its direct effects are felt in two ways: (1) The warm waters of temperate and tropical climates have greater solvent power than the colder waters of higher latitudes; (2) in warm regions the surface waters are enabled to exert their influence throughout the year, whereas in colder climates the ground is frozen during a portion of the year at least, the percolating of surface water is checked, and its chemical effects are decreased. More than this, precipitation is, in general, greater in low than in high latitudes, and takes the form of warm rain which saturates the ground instead of falling in great part as snow. Genial temperatures and abundant rain-fall are accompanied by luxuriant vegetation, which not only retains rain-water at the surface and allows it to percolate slowly downward, but imparts to it various organic acids, thus increasing its solvent power. The tendency of all these conditions is to produce greater chemical alterations in the rocks of warm, moist regions than in those of cold countries. As the regions of abundant rain-fall and rank vegetation pass by insensible gradations into cold or arid, barren regions, so the products of rock decay change by insensible gradations from regions like the southern Appalachians, where they reach a maximum, to other areas where they are for the most part wanting.

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[1] Rept. on the Geol. of Trinidad, London, 1860, p. 70.

The intimate connection between existing climatic conditions and rock decay has been clearly recognized by F. von Richthofen,[1] who states that—

> Weathering, in fact, becomes in large measure a climatic phenomenon. In moist and hot regions it is accomplished easily and rapidly; in hot and dry regions it seems to play an unimportant part, and where high degrees of cold prevail even an abundance of water is unable to produce it in any but an insignificant amount. Beneath the ever moist moss cushions of Finland and the northern Ural, granite shows undecomposed surfaces.

The conclusions presented above are quite the reverse of those arrived at by certain writers who have previously considered the subaërial decay of rocks. Thus, Th. Fuchs, in his essay entitled, "Zur Bildung der Terra rossa," in which the origin of the terra rossa, or Karst earth, of southeastern Europe is considered, says:

> One can hardly avoid the thought that the presence or absence of terra rossa is essentially dependent on climatic conditions; that it appears only where a dry climate prevails, and hence vegetable growth is scanty, whilst it can not appear where there is a moist climate, luxuriant vegetation, and consequently a greater accumulation of humus substances produced by both causes.

The greater extent of subaërial rock decay in the Southern than in the Northern States has been forcibly stated by W. C. Stubbs,[2] in reference to the formation of soils from the crystalline rocks of the southern Appalachian region, as shown in the following quotation:

> * * * Decomposition of these rocks in southern latitudes has proceeded much farther than with same rocks in higher latitudes, and therefore has given us deeper soils. It is difficult to find in the North a soil over a few feet deep, while here it is not uncommon to find in railroad cuts, wells, etc., disintegrated strata to the depth of thirty, fifty, or even seventy-five feet. This can be accounted for to a large extent by climatic influences. The warm waters, charged with carbon dioxide, percolating throughout the year the easily permeable strata, act continuously as a chemical agent in the work of disintegration; while farther north not only the amount of water, the temperature, and the chemical activity are reduced, but for one-half of the year the soil is locked up by frost from all access of decomposing agencies.

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[1] Führer für Forschungsreisende, Berlin, 1886, p. 100.

[2] The soils of Alabama, in Benney's Hand-book of Alabama, Mobile, 1878, p. 199.

The conclusions expressed in the above quotation have been cited with approval by F. H. Storer[1] in a note on rock disintegration in hot, moist climates. Very decided exception to these views has been taken by T. Sterry Hunt,[2] however, who insists that "present climatic differences have nothing to do with the fact that similar rocks are in one area covered with the products of decay and in another are wholly destitute of it." Hunt calls attention to instructive instances (some of which apparently admit of other interpretations) where ancient land surfaces have been protected beneath later formations, showing that subaërial decay took place during past geologic ages. He also points out that the rocks of the metamorphic portion of the Appalachian region have been exposed to atmospheric influences for a very great length of time.

The high antiquity of the residual clays of the Southern States is discussed in an earlier article by the same author,[3] in which the opinion is expressed that the chemical decomposition of the rocks referred to was "effected at a time when a highly carbonated atmosphere and a climate very different from our own prevailed."

The assertion that the accumulation of the residual clays now forming the surface of our country over thousands of square miles took place when the climate and the composition of the atmosphere were very different from what they are at present, carries back the origin of these deposits to an age geologically so remote, that it antedates the very origin of the rocks from which the residual clays were derived. It may be asked what was the time "when a highly carbonated atmosphere and a climate very different from our own prevailed?" Certainly not in the Tertiary, for our country was then clothed with forests closely resembling those now growing, and inhabited by land animals in great numbers that could not have differed markedly in their habits of life from existing mammals. These same arguments apply, less positively, to the Cretaceous, Jurassic, and Triassic periods. It is believed by certain geologists that the luxuriant Carboniferous forests flourished in an atmosphere more highly charged with carbonic acid than at present. It seems, therefore, that the "great antiquity" of the residual clays claimed by Hunt must refer to the Carboniferous or to pre-Carboniferous ages; that is, to a time preceding the deposition of the rocks of the Newark system, and antedating the upheaval of the strata in which the Great Appalachian Valley has been eroded.

Still further evidence bearing on this question is furnished by the red earths of Bermuda, Santo Domingo, Trinidad, Jamaica, etc., which have resulted from the decay of Tertiary or post-Tertiary limestones.

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[1] Science, vol. 1, 1883, p. 39.

[2] The decay of rocks geologically considered; in Am. Jour. Sci., 3d series, vol. 25, 1883, pp. 190–213.

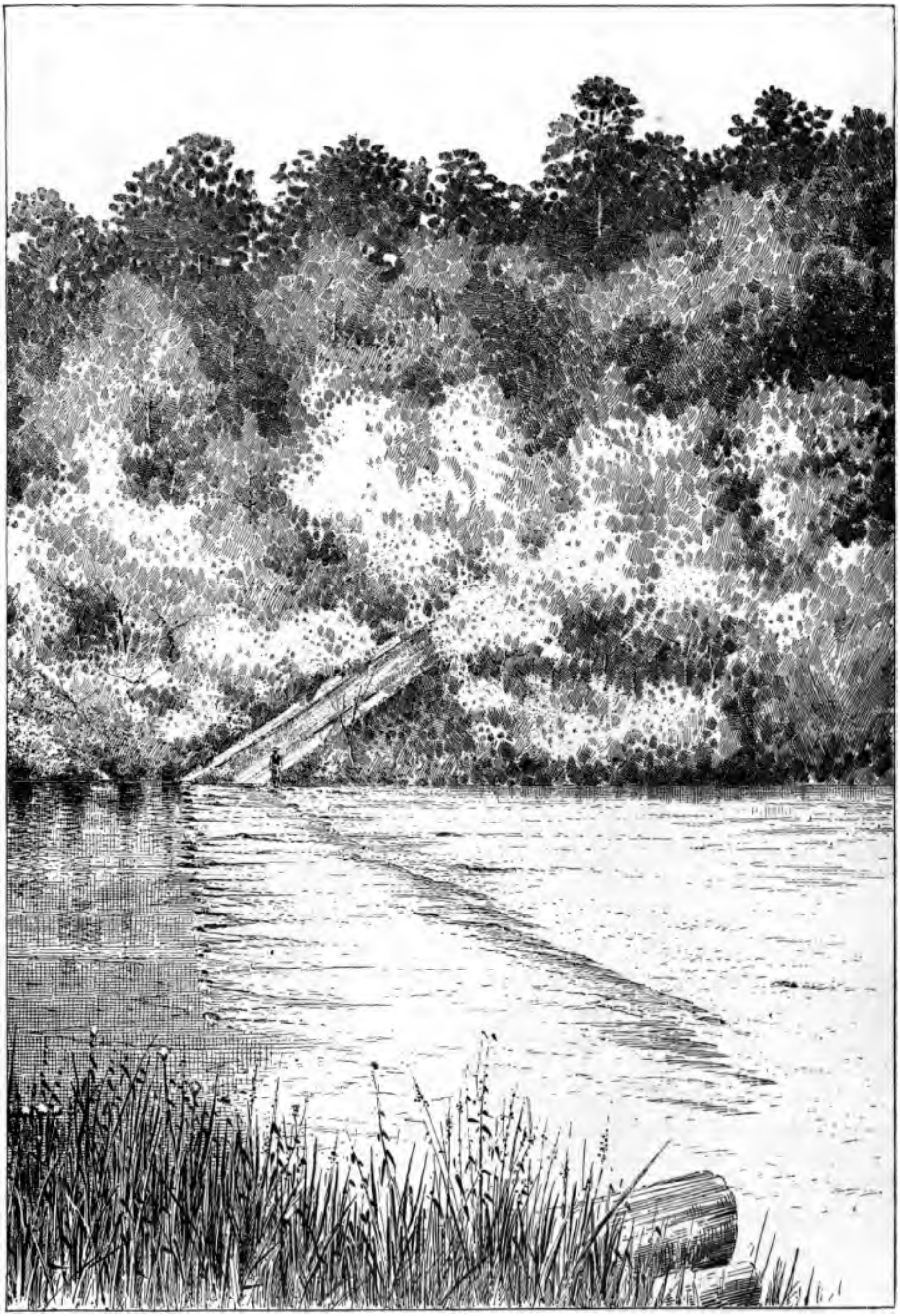
[3] Proc. Boston Soc. Nat. Hist., vol. 16, 1873–'74, pp. 115–117. See also "The disintegration of rocks and its geological significance," by the same author, Proc. Am. Assoc. Adv. Sci., 23d (Hartford) meeting, 1875, pp. 39–41.

It must be admitted by every geologist that a chemical alteration of surface rocks has been in progress from the first appearance of land on the earth to the present day, and may have been more active in past ages than now. Denudation has accompanied decay, however, and the residual deposits now remaining represent the net excess of disintegration and decomposition over transportation. In no region of any considerable extent is denudation so limited that the residual deposits formed during past geological ages can be expected to have withstood denudation and to have remained intact to the present time, unless they have been protected by subsequent deposits, preserved in caves, or otherwise sheltered. We must conclude, therefore, that such deposits now found at the surface throughout the southern Appalachian region have been formed during comparatively recent geologic times and that their accumulation is still continuing. This conclusion is enforced by the fact that many thousands of feet of rock have been removed from large portions of the Appalachian belt since the elevation of the mountains, and that hundreds and probably thousands of feet of strata have been eroded from the Atlantic border since the upheaval of the rocks of the Newark system.

The observed increase in the decay of the rocks as one travels southward along the unglaciated portion of the Appalachian region, and the occurrence of characteristic residual clays on the west slope of the Sierra Nevada, where a comparatively moist climate prevails, certainly seem to indicate that rock disintegration and decay are intimately related to the humidity and the temperature of the present climate. Before this conclusion is accepted, however, another hypothesis should receive attention.

EFFECTS OF GEOLOGICALLY RECENT OROGRAPHIC MOVEMENTS ON THE DISTRIBUTION OF THE RESIDUAL DEPOSITS OF THE APPALACHIAN REGION.

Throughout the Appalachian region traversed by me in 1885, 1886, and 1887 the streams flow over rocky beds and are broken here and there by cascades, caused by layers of rocks harder or more insoluble than their neighbors, as illustrated by Plates IV and V. The fact that the streams flow over rocky beds has been observed throughout the Appalachians and the adjacent Piedmont region from Pennsylvania southward, and at many localities in the northern part of the same belt as well. It is apparently safe to say that the Appalachian streams at the present time are deepening their channels. In other words, the present drainage has not reached a base level of erosion, and has probably been affected by a comparatively recent change in the level of the land, which has caused a renewal or a continuation of corrasion. This change must have been comparatively recent, for the reason that if the land had been stable for a long time, geologically



MAYO RIVER, NORTH CAROLINA, ILLUSTRATING THE MANNER IN WHICH THE RIVERS OF THE PIEDMONT REGION ARE ERODING THEIR BEDS.

The rocks producing the rapids are Newark sandstones.

speaking, the streams would have reached the limit to which they could deepen their channels and would be free from falls. This statement applies, however, only to that portion of the Appalachian belt where the drainage has not been affected by glaciers. Exception is also made of localities like Lookout Mountain, which have been left in relief by the more rapid denudations of surrounding areas. The fact that many of the Appalachian streams are flowing through narrow cañons, instead of broad valleys, likewise indicates that a base level of erosion has not been reached.

In reference to the rate at which the streams are now deepening their channels, there is apparently little if any difference in the various portions of the Appalachian belt. A critical examination might perhaps show, however, that the streams at the North are cutting more rapidly than those at the South, and that the change from north to south is gradual. As will be seen a little later, this would be in harmony with the evidence that a recent elevation of the northern part of the Appalachians has taken place.

When we consider the terraces bordering the present streams, which record former changes in the level of the land, a marked difference is at once apparent between the extreme portions of the Appalachian belt. The stream valleys at the north are terraced. In the central portion of the region the terraces are fewer and more obscure than at the north. Southward, below the James, for example, terraces are wanting, or if occasionally seen they are obscure and difficult to distinguish. The presence of stream terraces at the north and their absence at the south indicate that there has been a recent elevation of the northern portion of the Appalachian belt.

An increase in elevation of a large area would be followed by more rapid stream erosion, consequent on increased declivity, among the first effects of which would be the removal of residual deposits from all regions having free drainage. The comparatively recent elevation of the land indicated by the terraces along the streams north of the James may therefore account, at least in part, for the scarcity of residual clays in the central and northern portions of the Appalachian belt.

If we assume that a sheet of residual clays of uniform thickness covered the Atlantic States previous to the Glacial Epoch, the present unequal distribution, disregarding for the moment climatic influences, may be referred in part to each of two causes: First, the removal of the residual deposits from the region occupied by ice through glacial action. That this would be the result of the advance of a vast ice sheet is conceded by every one who has investigated the question, and need not claim further attention at this time. Second, the thickening of the sheet of residual clay toward the south from the southern margin of the glaciated area would be due to unequal erosion produced by unequal upheaval of the Appalachian region.

The effects of climate and of upheaval on residual deposits thus furnish two hypotheses to account for the observed increase in thickness of the products of decay as one travels southward along the unglaciated portion of the Appalachian belt. These may be called: (1) the hypothesis of climatic variation; (2) the hypothesis of orographic movement.

The correct explanation of the facts observed in reference to the present distribution of residual deposits in the region under discussion probably lies in part in each of these hypotheses.

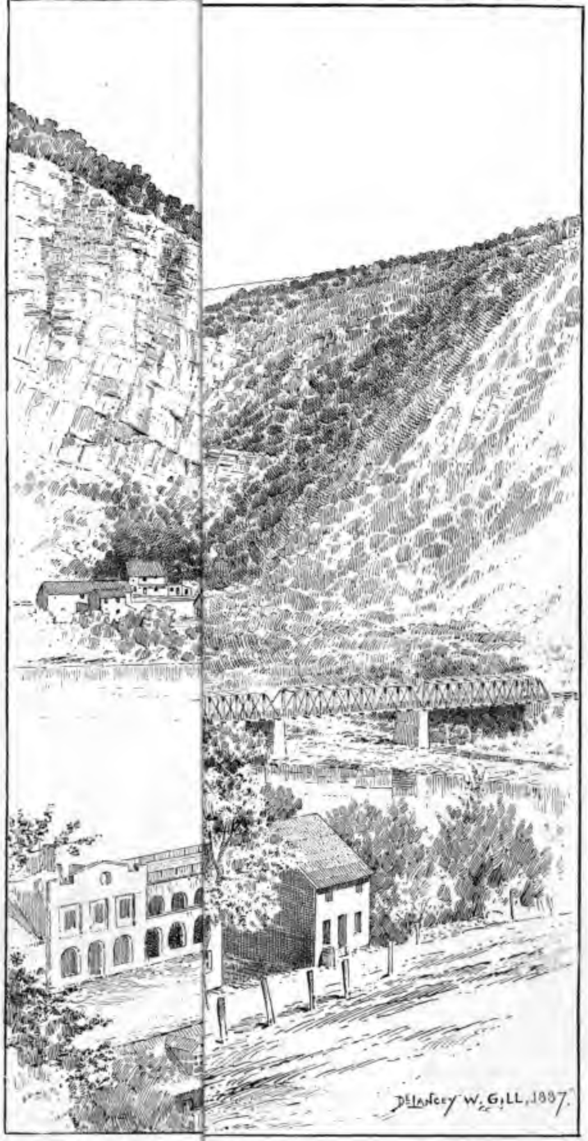
In a belt of country extending more than a thousand miles from north to south and composed from end to end of similar rocks, as in the case in the Appalachian belt, it is safe to assume, in view of the facts already presented, that weathering will be unequal, owing to variations of climate. In the case before us, however, the conditions have been varied by oscillations of the land at a late date in the period of decay, which have accelerated denudation over the northern portion of the belt.

My conclusion from the facts already presented, together with the impressions received in the field, but difficult to formulate, is that each of the causes mentioned above has had its share in producing the observed differences in the distribution of the residual deposits throughout the middle and southern portions of the Appalachian region, but that the controlling influences were temperature and humidity.

It is not to be inferred from what has been said in the preceding passages that no decay has taken place in the rocks of the Northern States. On the contrary, we have evidence, especially in the driftless area of the Upper Mississippi Valley, that the rocks at the North were disintegrated to a considerable depth before the advent of the great ice sheet; but, judging from the condition of the unglaciated area, this change was not nearly so pronounced as at the South. The ice erosion of the Glacial Epoch not only removed and commingled the previously formed residual deposits, but planed away the country over a vast area to a greater depth than had been reached by the previous decay. This is shown by the freshness of the rocks on glaciated surfaces and by the solidity of many of the bowlders composing the moraines left by the ice.

The conclusion that subaërial decay is intimately related to existing climatic conditions does not appear to hold in Southeastern Europe and in portions of India, where, it is reported, extensive residual deposits occur in connection with comparatively dry climates. Very recent changes in the humidity of these regions may have occurred, however, which would remove the objections presented by their present condition.

The diversity of opinion indicated by the citations given above encourages a hope that the subject treated in this paper may receive greater attention from geologists, and that observations may be multi-


DELANCEY W. GILL, 1887.

plied with reference especially to the geographic distribution of residual deposits and to the chemical changes that they have undergone. The mechanical condition of residual deposits is also worthy of attention, for the reason that the decay of rocks furnishes the raw material, so to speak, for the formation of sedimentary strata, and a knowledge of its characteristics will assist geologists in determining the nature of the parent rocks from which ancient clastic beds were derived.

THE SOLUBLE PORTIONS OF ROCKS.

I have approached the study of the chemical alteration of rocks by examining the deposits remaining after rocks have been exposed to a mild solvent, i. e., ordinary surface water, for a great length of time. The investigation might have been commenced by studying the soluble instead of the insoluble portions of rocks; in fact this is the usual method, as is shown by the many essays already written on the chemistry of natural waters. The problem is concerned mainly with solubility combined with oxidation. The mineral matter dissolved in river waters represents the soluble, and residual deposits represent the insoluble portions of rocks. It is evident that the average composition of the residual deposits of a given region should be the complement of the mineral matter contained in the streams flowing through it. Together these should represent the average composition of the rocks of the area in question.

It is not my aim to undertake the study of the chemistry of natural waters—this has already been done by able chemists; but it is of interest, in connection with an examination of residual deposits, to know what mineral substances are commonly contained in river waters. For this purpose the following analysis of the water of the James River,[1] Virginia, which drains a region covered throughout with residual deposits, is inserted. The sample analyzed was collected at Richmond, October 24, 1876, after a light rain.

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[1] Analysis reduced to parts per thousand. From Annual Report of the Richmond [Va.] Board of Health for 1876. See also Geological History of Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 173, 174.

Analysis of the water of James River, Virginia. By W. H. Taylor.

Constituents.	Parts per thousand.
Sodium (Na)	.00244
Potassium (K)	.00251
Calcium (Ca)	.01284
Magnesium (Mg)	.00377
Chlorine (Cl)	.00105
Carbonic acid (CO_2)	.02954
Sulphuric acid (SO_3)	.00363
Phosphoric acid (HPO_3)	trace
Nitric acid (NO_5)	.00231
Silica (SiO_2)	.01024
Alumina (Al_2O_3)	.00041
Sesquioxides of iron (Fe_2O_3)	.00072
Sesquioxides of manganese ($Mn_2\,O_3$)	
Ammonia (NH_4)	.00001
Organic matter	.00299
Total	.07246

From the analysis of the waters of twenty American rivers it has been ascertained that the average of solids in solution is 0.15044, and the average of calcium carbonate 0.056416 part per thousand.[1] The average of total solids in solution, as derived from a table of forty-eight analyses of European river waters given by Bischof,[2] is 0.2127, and the average of calcium carbonate 0.1139 part per thousand.

The analyses of thirty-six European river waters, published by Roth,[3] including some of those tabulated by Bischof, give 0.2033 part per thousand as the average of total solids and 0.09598 part per thousand as the average of the calcium carbonate. In both American and European river waters, so far as can be ascertained from the data in hand, the average of total solids in solution is 0.1888 and the average of calcium carbonate 0.088765 part per thousand. In a general way, therefore, the amount of calcium carbonate dissolved by river waters may be taken as about one-half the amount of total solids in solution.

The amounts given above seem insignificant when considered by themselves, but when we remember the vast volume of water discharged by rivers every day, the quantity of solids in solution thus transferred from the land to the sea is seen to be so great, even in a single year, that we are unable to comprehend the meaning of the figures that indicate its magnitude.

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[1] Geol. Hist. Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 173, 174.

[2] Chemical Geology, English edition, London, 1854, vol. 1, pp. 76, 77.

[3] *Chemical Geology,* vol. 1, Berlin, 1879, pp. 456, 457.

For example, it has been estimated that the Thames, England, carries daily 1,682 tons of inorganic matter in solution, of which 1,121 tons are calcium carbonate. The Croton, New York, carries daily 183 tons of inorganic matter in solution, of which 47 tons are calcium carbonate; the Hudson, New York, 4,000 tons, of which 1,200 tons are calcium carbonate; the Mississippi 309,100 tons, of which 137,419 tons are calcium carbonate. The Mississippi alone carries annually nearly 113,000,000 tons of mineral matter in solution in addition to its visible load of silt carried in suspension, which is about four times as great.[1]

From another analysis T. Millard Reade[2] has computed that the Mississippi discharges annually 150,000,000 tons of solids in solution. As this computation and the one presented above are each based on a single analysis, the discrepancy in the results reached is not remarkable.

Computations of this nature might be multiplied indefinitely, but the brief statements already given are sufficient to show what becomes of the vast quantity of soluble matter removed from the land in connection with the formation of the residual deposits which impart their characteristic color to large portions of the earth's surface.

CHARACTERISTICS OF RESIDUAL CLAYS.

A few chemical analyses of residual clays have been given in the preceding pages in connection with descriptions of the decay of rocks at various localities, but it is of interest to assemble these and other analyses of a similar character in a tabular form, in order to show especially the close similarity that exists in the composition of residual deposits of various countries, even when derived from rocks which differ widely in both chemical and physical properties.

In the following table, the analyses numbered 1, 2, 3, and 7 have been given in the preceding portion of this paper. No. 1 shows the composition of a red clay derived, as nearly as can be determined, from chloritic schist. No. 2 is an analysis of decomposed trap (dolerite) from the Newark rocks at Wadesborough, N. C. No. 3 gives the composition of dark red residual clay derived from Trenton limestone near Lexington, Va. No. 4 shows the average composition of four samples of residual clay formed by the decay of limestone in the driftless area of Wisconsin.[3] No. 5 is the analysis of a kaolin, now used in the manufacture of pottery, from Chestnut Hill, Lancaster County, Pa. This is also a residual clay, and is considered by J. P. Lesley as having been derived from "potash (orthoclase) feldspar rock." The analysis is by F. H. Genth.[1] No. 6 is the analysis of a typical kaolin or china clay,[2] the composition of which may be represented thus: $^{2}SiO_2, Al_2O_3, ^{2}H_2O$. No. 7 a red clay derived from the decay of Knox dolomite, Morrisville, Ala.

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[1] For references, see Geol. Hist. Lake Lahontan, Mon. U. S. Geol. Survey, No. 11, pp. 174, 175.

[2] Denudation of the two Americas. Presidential address; Proc. Liverpool Geol. Soc., vol. 5, 1884-'85, pp. 8-45.

[3] Published by Chamberlin and Salisbury, in the Sixth Ann. Rept. U. S. Geol. Survey, p. 250.

Analyses of residual clays.

Kaol China Ala

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
SiO_2	54.54	39.55	43.37	55.73	67.1	46.33	55.42
Al_2O_3	26.43	28.76	25.07	18.16	20.1	39.77	22.17
Fe_2O_3	9.04	16.80	15.16	10.57	3.9	....	8.30
FeO	....	....	....	0.63	....	....	Trace.
H_2O	9.87	13.26	12.98	[a] 9.40	5.9	13.96	9.86
MnO	....	Trace.	....	0.03	....	....	....
CaO	....	0.37	0.63	0.99	0.1	....	0.15
MgO	....	0.59	0.03	1.12	0.7	....	1.45
Cr_2O_3	....	Trace.	....	....	....	....	....
Na_2O	....	Trace.	1.20	1.44	Trace.	....	0.17
K_2O	....	Trace.	2.50	1.24	2.0	....	2.32
P_2O_3	....	0.10	....	0.03	....	....	Trace.
TiO_2	....	0.64	....	0.26	....	....	Trace.
CO_2	....	....	....	0.35	....	....	....
C	....	....	....	0.46	....	....	....
Total	99.88	100.07	100.94	100.41	99.8	100.00	99.84

[a] Contains H of organic matter.

This table might be increased almost indefinitely, if so desired, by consulting reports on agricultural geology and other similar treatises. In Eugene A. Smith's report on the Agricultural Features of Alabama,[3] especially, there are numerous analyses of soils formed of residual clays, which agree very closely in chemical composition and physical characters with the examples presented above.

In the analyses given in the table, it will be noticed that silica, alumina, ferric oxide, and water make up over 90 per cent. of the residual clays examined. As the samples analyzed are typical of their class and agree essentially with many other analyses of a similar character with which they have been compared, we may conclude that residual clays in general are ferruginous kaolins of varying degrees of purity. They differ from ordinary brick-clays since they have resulted from chemical decomposition and not from mechanical disintegration. They are hydrous and have a very low percentage of soluble salts; in both of these particulars they differ from clays produced by mechanical means. The fine sediment deposited by many glacial streams is remarkably claylike in its physical properties, but chemically it has essentially the same composition as the rocks from which it was derived. The differences between glacial and residual clays have been clearly stated by Chamberlin and Salisbury in their description of the unglaciated areas of the Upper Mississippi Valley, previously referred to.

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[1] Annual Rept. Geol. Survey Pennsylvania for 1885, p. 588.

[2] A. H. Green's Physical Geology, 3d ed., London, 1882, p. 174.

[3] In Geol. Survey Alabama, Rept. for the years 1881 and 1882.

The close similarity between the analyses of residual clays from various localities and from diverse geologic formations, indicated in the table, is found only when the chemical decomposition, or decay, is far advanced; otherwise the residual material may contain fragments of undecomposed rock. Under the microscope a typical residual clay should show only amorphous matter, free from particles of crystals and rock fragments. In the examination of a large number of samples this complete disintegration was seldom seen, however, as the clays nearly always contain quartz fragments and not infrequently particles of other minerals.

In color, residual clays are usually red, owing to the oxidation of the iron contained in the minerals composing the original rock; but in some cases they are mottled red and yellow, or may have various shades of yellow, brown, purple, etc. It is the characteristic red color which gives the name terra rossa to the residual clays of Southern Europe. Unweathered clastic rocks, on the other hand, are usually gray, green, blue, etc., but are seldom red. All who traverse the Great Appalachian Valley or the Piedmont region of Virginia, the Carolinas, Georgia, and Alabama, must be impressed by the charming bits of color imparted to the landscapes by the red clays of the roads and fields. In dry weather this material is usually compact and hard, forming excellent roads, but during the rainy season the highways become soft and almost impassable. Among the many differences to be seen between a glaciated country, like New York and the New England States, and a region in which atmospheric decay has progressed uninterruptedly for geologic ages the colors of the soil and the prevailing tints of the landscape are not the least conspicuous. In glaciated regions the landscape is mostly sombre, usually gray, when not covered with vegetation, excepting where the rocks themselves are red, as in the Newark areas of New Jersey and the Connecticut Valley. But on an old land surface, where decomposition is far advanced, brilliant dyes are to be seen wherever the turf is broken. Although the rich color of terra rossa is especially pleasing to those who are sensitive to the play of tints in a landscape, yet at times it serves only to increase the ugliness of unsightly cuts and embankments. In such instances it seems as if the earth bled from the wounds inflicted by man.

The contrast in color between northern and southern landscapes in the Appalachian belt has recently been explained by W. O. Crosby, in an essay on the colors of soils,[1] on the assumption that the observed difference of color has resulted directly from differences of temperature between the North and the South. In the essay referred to it is urged that the higher temperature at the South is capable of dehydrating the ferric oxides impregnating the soils, thus changing their color from yellow to red; and also that the red color of residual clays is a superficial phenomenon, confined to the immediate surface of the deposits.[2] My own observations do not confirm these conclusions. At many localities in the Appalachian region south of Pennsylvania where residual deposits were observed, the characteristic red color was seen to extend far below the surface, and as a rule to reach the bottom of fresh exposures. In many localities the color of the residual clays at a depth of 20 or even 50 feet is similar, so far as the eye can distinguish, to the color in the same sections only a foot or two below the surface. The great depth to which the red color extends renders it evident that it can not be directly dependent on solar heat. Again, over considerable areas in the South the surface clays are various shades of yellow, which would not be expected if the red color of adjacent fields is due to temperature.

Moreover, the dehydration of ferric oxide, as stated by Crosby, takes place at a certain temperature (about that of boiling water in laboratory experiment), but is not considered as resulting from a high mean annual temperature. Under this hypothesis we must consider, therefore, that the heating of the earth during the summer months is sufficiently high in the Southern States to dehydrate ferric oxide, and that at the North this is not the case. Certainly a very delicate adjustment of chemical conditions is here postulated. Having experienced the summer's heat both at the North and at the South, it seems to me to be doubtful whether the soil in northern Alabama, for example, is more highly heated during the summer than the soil in Pennsylvania and New Jersey. Exact observations on this point are not at hand.

The description of the colors of the residual clays in the metamorphic region of Alabama, quoted on pages 18–20, should be read in connection with the discussion here referred to.

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[1] Proc. Boston Soc. Nat. Hist., vol. 23, 1875, pp. 219–222.

[2] This hypothesis has been applied by its author in an article on the "Geology of the Black Hills of Dakota" (Proc. Boston Soc. Nat. Hist., vol. 23, p. 509) in explaining the origin of the color of the Red Beds of the Rocky Mountain region which it is claimed "depend [for their color] largely upon an excessively hot and dry climate; and in the repeated exposures of the Red Bed sediments during their deposition to a hot and arid atmosphere." In opposition to this argument attention may be directed to the playa-lake deposits of Nevada and Arizona which are now forming under the atmospheric conditions named above, but which are always creamy white in color. The temperature to which these beds are exposed during the summer months very commonly ranges from 110° to 120° Fahr. in the shade—far exceeding any temperature reached in the southern Atlantic States.

ECONOMIC PRODUCTS OF RESIDUAL CLAYS.

The most important economic products of the residual clays in the southern Appalachian region is the iron ore they contain. This is often scattered irregularly through the terra rossa in concretionary masses varying from a small fraction of an inch up to a foot or more in diameter, which frequently have a glossy surface and bear a somewhat close resemblance superficially to certain meteorites. At other times the limonite is in irregular tubular masses of many tons weight. In both instances there is abundant evidence that the ore was deposited during the accumulation of the residual clays in which it occurs. Several of the iron furnaces of Alabama and Georgia are supplied from ore of the nature described. Manganese ores of varying degrees of purity are also an accompaniment of residual clays of the Southern Appalachian region.

In a few localities in the region underlaid by the Lower Silurian rocks of the Great Appalachian Valley the residual clays contain baryte in considerable quantities. In these instances the baryte is a residual deposit, having been left as the limestone in which it was originally formed was removed in solution. The red soil derived from the decay of this same limestone sometimes carries irregular fragments of galena, which formerly filled cavities of which they retain the form, and, like the baryte, they were left when the more soluble portion of their matrix was removed. The occurrence of gold in residual clays has already been referred to. At some localities terra rossa has been utilized in the manufacture of bricks.

II. ORIGIN OF THE RED COLOR OF CERTAIN FORMATIONS.

A HYPOTHESIS PROPOSED.

It follows as a corollary from what has been said in a preceding portion of this paper that the iron-stained sands resulting from the subaërial decay of crystalline rocks will furnish the material for red sandstones and shales when deposited in basins holding water. Exceptions may occur when the débris is subjected to sufficient attrition to remove the incrustations of ferric oxide or exposed to the action of chemical agents having the power to dissolve it.

It is well known that the red and brown colors of the Newark sandstone, and of many other similar sandstones and shales, are due to incrustations of ferric oxide which coat the surfaces of the grains of quartz and feldspar forming the strata and cement them together.[1]

In order to verify the conclusions of previous observers in connection with this subject an examination was made of thirty thin sections of sandstone collected by the agents of the Tenth Census from quarries at various localities in the Newark areas from Massachusetts to North Carolina. All of the specimens examined were composed principally of angular quartz grains, with which were frequently mingled fragments of feldspar, hornblende, mica, etc. In several examples the rocks were gray, and derived their color from the inherent tints of the fragments composing them. In most instances, however, they had the brownish red color characteristic of the Newark system in general, and under the microscope revealed the fact that their color was not inherent in the particles composing them, but was due to a fine, amorphous, clay-like coating which enveloped the grains and filled the intervening spaces. The edges of the quartz grains, as seen in thin sections, are sharply defined by a red line, the outer border of which is less definite than that next the grains, and merges with the lighter red material filling the interspaces. The coloring matter which adheres to the grains is not composed of concentric layers, and does not show a crystalline structure—facts which indicate that it was not deposited from solution. The rifts and crevices in the quartz grains are filled with material of the same character as that which stains their surfaces, and was evidently introduced from the outside.

That the characteristic color of these sandstones is due to material coating the grains of which they are composed, and filling the spaces between them, may also be shown by digesting the rocks in acids, when the color disappears and leaves the sands with their normal tints.

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[1] The appearance of a thin section of these sandstones when examined with a microscope has been described and illustrated by G. W. Hawes, Geol. New Hampshire, *vol. 3, 1878, part 10, p. 240,* Plate XII, Fig. 6.

The coloring matter of the Newark sandstones thus agrees with the coloring matter of residual deposits resulting from the subaërial decay of crystalline rocks not only chemically, but also in the manner in which it incrusts the grains.

We know that the débris composing the stratified rocks of the Newark system was derived from the waste of the surrounding crystalline areas. It therefore seems safe to conclude, especially when we consider the nature of the subaërial deposits now being produced by the decay of the crystalline rocks of the southern Appalachians, that the material composing them acquired its red color during the disintegration of the rocks from which it was derived. The red cementing material is residual clay or terra rossa.

If the hypothesis here advanced in reference to the origin of the red color of the Newark sandstones is sustained by future investigations, it will follow that the débris composing these rocks was deposited in lakes or estuaries where it was not subjected to prolonged washing by waves or exposed to the action of natural reagents which have the power to dissolve it. Had the débris been deposited in the ocean and exposed to the action of waves and currents, the sands would have been more thoroughly assorted than we now find them. We should expect, also, that the attrition produced by the wash of the waves under such circumstances would have scoured off the incrustation of ferric oxide. A microscopical examination of a number of samples of the sand obtained by washing residual deposits failed to show that the iron-stained grains thus separated were more angular than the sand grains in an average sample of Newark sandstone. This indicates that the latter was deposited rapidly and not worn and rounded by prolonged wave action.

The chemical reaction of sea water on incrustations of this character has not been investigated.

The character of the deposits that result when débris is contributed to swamps or lakes rich in organic acids is illustrated by the middle or carbonaceous member of the Newark system exposed in the coal fields of Virginia and North Carolina. These beds are sometimes highly charged with iron, but it is combined with sulphuric and carbonic acids. The rocks are therefore not red and the grains of sand composing the strata in part are not incrusted in the manner observed in the red sandstone.

The assorting of residual deposits formed by the subaërial decay of crystalline rocks, like those composing the Appalachian crystalline belt, would afford material for the formation of stratified beds of diverse lithological character. When the rocks were much decomposed beds of iron-stained sand would predominate, interstratified with layers of red clay formed by the accumulation of finer and more thoroughly decomposed material washed from the land. When the parent rock was disintegrated without suffering marked decomposition, light-colored and less homogeneous beds would be formed. The more thorough the subaërial decay, therefore, the more homogeneous and the more ferruginous would be the resulting sedimentary beds.

When the residual deposits of an ancient land surface contribute to the filling of lakes or estuaries the shore deposits should be coarse and contain fine red sediment in the interstices between the pebbles. Near the land such a formation would probably be a light-colored conglomerate or breccia, cemented with fine ferruginous clay; farther seaward the sediment should not only be finer but also more homogeneous and more completely iron-stained.

It has been remarked by several geologists that the sandstone forming the lower portion of the Newark system of the Southern States is more highly colored than the similar rocks in the upper portion of the same formation. This may be due to a removal of the more thoroughly decomposed residual deposits from the surrounding shores before the upper portion of the series was laid down.

F. von Richthofen's[1] view of the possible origin of red deposit agrees essentially with the hypothesis here proposed, as is indicated in the following citation, which follows a statement that great quantities of the residual soils of Brazil are now being carried to the sea and deposited as red sediments on the floor of the ocean. He says:

> A far more prominent part would be played by the laterite if a wave of abrasion swept over Brazil scouring away the red soil formed in the course of centuries, in order to allow its redeposition in the overplaced sediments (*transgredirenden Sedimenten*). This has been the origin of many formations of by-gone time, and it is proper to note that the mightest accumulations of red masses of sediments occur in the strata of the Rothliegende, which often appear in the manner of transgressions, and that these strata were preceded in time by the Carboniferous epoch, in which, to judge from analogy with the present time, there must have occurred the most intense deep decay of rock, involving the formation of laterite.

In Part I of this paper it has been shown that the residual deposits of warm, humid regions are red, and that the corresponding deposits of arid regions are light colored, usually gray or yellow-brown.

It seems to follow from this that the red rocks of the Newark system and of the Rocky Mountain Red Beds were formed from the débris of lands that had been long exposed to the action of a warm, moist atmosphere. This same suggestion has been made by Richthofen, as is shown by the citation just given.

The conclusions presented in the past few pages will perhaps appear more definite if we consider briefly the various hypotheses that have previously been advanced to account for the red color of certain formations.

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[1] *Führer für* Forschungsreisende, Berlin, 1886, pp. 466,467.

PREVIOUS HYPOTHESES.

A. C. Ramsay,[1] after studying the Old Red Sandstone and other formations in Europe which are largely composed of iron-stained rocks, advanced the hypothesis that lake deposits are usually red, and that their color is due to the presence of peroxide of iron, "the iron probably having found its way into the water as a carbonate, which, by contact with the air, afterwards became peroxidized, and incrusted the sedimentary grains as a thin pellicle."

A study of lacustral deposits at many points in the United States has shown that the generalization quoted above can not be accepted without important qualifications. The Quaternary and Tertiary lacustral beds of this country are light colored, almost without exception.[2] The grains of sand composing them in large part are not incrusted with ferric oxide. The sediments now forming in the saline and alkaline lakes of the arid region of the Far West are not iron-stained and do not differ in this respect from the sediments now being deposited in the Laurentian lakes.

In describing the Tertiary and post-Tertiary lake deposits of the western part of the United States, F. V. Hayden[3] says:

> The prevailing color is light brown-gray or nearly white, perhaps in some instances a cream color. There is a remarkable similarity in the color as well as the composition of these deposits all over the West, in Montana, Oregon, New Mexico and Texas.

F. von Richthofen[4] describes the lake loess of China, which appears to be similar in every way with the playa deposits of the arid region of the United States, as being whitish yellow in color.

The observations indicate that the reverse of Ramsay's hypothesis is true, namely, that lacustral deposits in general are not characterized by a red color.

All the examples given above of lacustral deposits now forming, however, are located in regions that do not give evidence of having suffered marked subaërial decay. The existing lakes of this country do not receive the débris of lands that are deeply covered with residual deposits. In the South Atlantic States, where the greater portion of the country is buried beneath decomposed rocks rich in iron, the stream deposits are largely iron-stained sands, containing grains of feldspar and mica. Were there any lake basins in this region it is evident they would become filled with material of the same character as that now forming the stream beds and flood plains. Lacustral deposits accumulated under such conditions would comprise iron-stained sands interstratified with layers of red clay, etc., which, in general, would be practically identical with the rocks of the Newark system.

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[1] On the physical relations of the New Red Marl, Rhætic Beds, and Lower Lias. Quart. Jour. Geol. Soc. London, vol. 27, pp. 189-206. Also, On the Red Rocks of England of older date than the Trias. Ibid., 241-256.

[2] The only exception known to me is the red clay deposited during the Pleistocene expansion of Lakes Superior and Michigan. Geological Survey of Wisconsin, 1873-'79, vol. 1, p. 292.

[3] Notes descriptive of some geological sections of the country about the headwaters of the Missouri and Yellowstone Rivers. Bull. U. S. Geol. Geog. Survey Terr., Washington, 1876, vol. 2, p. 201.

[4] China, vol. 1, p. 81.

The hypothesis proposed by Ramsay necessitates that ferrous carbonate should be contributed in solution to lakes of great size in sufficient quantity to saturate their waters, and that its oxidation or change to ferric oxide should go on more or less continuously throughout the time the sediments were accumulating. This process, if I understand it aright, would be practically the same as that by which bog ores are formed. This complicated series of chemical reactions might furnish an explanation of the color of local deposits, but it does not seem applicable to such great formations as the Old Red Sandstone of Europe or the Mesozoic red sandstones of this country.

J. W. Dawson,[1] in an article "On the coloring matter of red sandstones, and of grayish and white beds associated with them," states that the coloring matter of the Carboniferous sandstones, red conglomerates, etc., of Nova Scotia "is the peroxide of iron in a very fine state of division, having indeed rather the aspect of a chemical precipitate than of a substance triturated mechanically. In the clays and shales it is usually very uniformly diffused through the mass; in the sandstones and conglomerates it is principally contained in the argillaceous matter which occupies the interstices of sand and pebbles, and it also stains the surfaces of these fragments." Dawson supposes that the ferric oxide was derived from the oxidation, through the action of igneous agencies, of iron pyrites disseminated through the rocks from which the Carboniferous sandstones were derived. This view has been discussed at some length by A. A. Julien in his essay On the Geological Action of the Humus Acids,[2] who shows that the coloring matter in the rocks described by Dawson must have been derived from the decomposition of the hornblende, chlorite, orthoclase, and the iron garnets as well as the pyrites of the parent rock.

The conditions under which the Carboniferous sandstones of Nova Scotia received their red color were repeated in the same region when the Newark sandstones were deposited. In describing the latter rocks A. W. McKay observes:[3]

> The color of these beds seems to be derived from the iron contained in the neighboring metamorphic rocks. It occurs in these latter in three different forms: (1) There is

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[1] Quart. Jour. Geol. Soc. London, vol. 5, 1848, pp. 25–30. See also Acadian Geology, by J. W. Dawson, 3d ed., 1878, pp. 622–623, and On the parallelism of the rock formations of Nova Scotia with those of other parts of America, by the same author, Proc. Am. Assoc. Adv. Sci., 10th (Albany) meeting, part 2, p. 20.

[2] Proc. Am. Assoc. Sci., 28th (Saratoga) meeting, 1879, pp. 405, 406.

[3] The Red Sandstones of Nova Scotia. Rept. British Assoc. Adv. Sci., 35th (Birmingham) meeting 1865, part 2, p. 67.

a quantity of it distributed generally throughout the slates and shales, of which these strata are composed; (2) there are veins and beds of specular iron ore, as in the Devonian rocks of Nictaux; and (3) it occurs in the shape of bisulphide of iron or iron pyrites. When these metamorphic rocks were worn away the iron set free was oxidized by contact with the atmosphere and mixed up with sediment as it was laid down.

J. D. Dana[1] attributes the red color of the Newark sandstones to the oxidation of the iron which they contain, through the agency of the intruded sheets and dikes of trap.[2] As the red color is not confined to the vicinity of the igneous intrusions, and is disseminated with remarkable uniformity through great thicknesses of sandstone,[3] we are at a loss to see how the incrusting of the grains of sand with ferric oxide could have been brought about by the heat of the intruded rocks. This explanation fails entirely when applied to similar iron-stained sandstones which have not been disturbed by igneous injections. It also fails, in part at least, when applied to regions in which the trap is not intrusive, but was poured out as an overflow, and subsequently became buried beneath sedimentary deposits.

In another place Dana[4] refers the red color of the sandstones of the Connecticut Valley to an alteration of the iron they contain by the action of heat resulting from orographic movements.

As stated by him, the change produced by the tilting of the rocks of the region referred to into their present inclined position "stopped short of metamorphism, the sandstones being only reddened and partially solidified." Applying this hypothesis to the Virginia and North Carolina coal fields, where the strata are as highly inclined as in the Connecticut Valley, one would expect that the rocks would have the characteristic color found in other portions of the same formation, providing that a change in color resulted from the tilting of sedimentary beds. The facts are, however, that the carbonaceous rocks in the coal fields referred to show no alteration in color, and the coal they contain is still highly bituminous, except in the immediate neighborhood of trap dikes. That reddening is a general result of metamorphism, as is assumed in the quotation given above, can scarcely be accepted in the presence of so many examples of metamorphosed rocks that are not red.

The view that the red color of the Newark sandstones is due to the heat of the intruded trap was advanced in substance many years since by E. Hitchcock[5] and J. G. Percival.[6] That the trap could have been instrumental in producing the wonderful results assigned to it by the authors quoted above has been successfully refuted by W. M. Davis,[1] who has shown by observations made by himself and others, that as a general rule the baked strata near the trap are not so red as the unaltered layers farther away. Davis has also pointed out the fact that red sandstones occur in regions so far removed from igneous action that they could not be influenced by it.

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[1] Manual of Geology, 1875, p. 420.

[2] This hypothesis has also been controverted by Julien, loc. cit.

[3] Among the many illustrations of the thickness of the iron-stained rocks of the Newark system that might be given are the records of a well over 1,400 feet deep at Durham, N. C., in which the rocks, with some exceptions, are reddish brown and remarkably similar in composition from top to bottom. Other wells of still greater depth in New Jersey and the Connecticut Valley have given similar results.

[4] Am. Jour. Sci., 3d series, vol. 5, 1873, p. 431.

[5] Rept. on the Geol., Min., Bot., and Zool. of Massachusetts, Amherst, 1833, p. 242.

[6] Geol. Connecticut, New Haven, 1842, p. 430.

B. K. Emerson[2] attributes the red color of a portion of the sandstone of the Connecticut Valley to iron derived from volcanic dust thrown out of certain small volcanoes, the remnants of which he has recently discovered in Hampshire County, Mass.

G. H. Cook[3] has suggested in reference to the coloring matter contained in the Newark sandstones and shales of New Jersey, that the iron in the coloring matter with which the grains are incrusted was dissolved from the trap rocks of the region by percolating waters and redeposited in the sandstone. At least this is my interpretation of the following passage:

> The deep red color of this formation shows its large percentage of oxide of iron, which in some of the shales amounts to 10 per cent., though it is usually much smaller. It is in the form of oxide, and forms the paste or cement of the mass. Where did this iron ore come from? Very little is found in the gneiss from which the sandstone has been formed, and there is not much in the lower and light-colored beds of the sandstone. The trap contains magnetic iron ore in little particles; so much that almost any specimen of it powdered will yield some to the magnet, and the rock itself is quite magnetic; irregularly so, however, as it produces local attraction and disturbance of the surveyor's compass. Did the iron ore come from the same source which supplied the trap? It might have come thus, and, dissolved in water, it could have made the coloring material and furnished the precipitated oxide of iron. It is very evident that the high-colored sands in the Cretaceous and Tertiary formations were white when deposited and have been discolored by water containing oxide of iron; for we often find little nests of perfectly white sand surrounded on all sides by red sand full of oxide of iron; and in some cases a perfect shell of sand, cemented by oxide of iron into stone, is filled with a mass of loose sand. The same kind of agency has, undoubtedly, supplied the coloring substance of the Triassic rocks, though it appears to have been done at the time of its deposition.

The fact that the sandstones are not more highly colored in the neighborhood of the trap ridges than at a distance of several miles from them, as has already been shown, is in direct opposition to the hypothesis presented in the above quotation.

It is well known also that with the exception of samples taken from near the outcrops of the trap ridges in New Jersey, the microscope fails to show that these rocks have suffered to a marked extent by the solution of their constituents, as is also proven by the discovery of metallic iron in them.[1] Even if the whole of the iron contained in the trap rocks of New Jersey had been removed and redeposited uniformly throughout the accompanying clastic beds, it could scarcely have furnished sufficient ferric oxide to give them their characteristic colors. This statement is sustained, we believe, by the following considerations. An average of seventeen analyses of trap rock from New Jersey gives 12.6 per cent. of ferric oxide.[2] The per cent. of ferric oxide (Fe_2O_3) contained in five samples of Newark sandstone from New Jersey is as follows[3]:

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[1] On the relation of the Triassic traps and sandstones of the eastern United States; in Bulletin of the Museum of Comp. Zoölogy at Harvard College, vol. 7 (Geological series, vol. 1), No. 9, 1883, p. 300.

[2] *Gazetteer of Hampshire* County, Mass., 1654-1887. By W. B. Gray, Syracuse, N. Y. *(888), p. 18.*

[3] *Geol. New Jersey, 1868,* p. 338.

(1) Brown sandstone from Whitehall	3.83
(2) Brown sandstone from Wortendyke	3.00
(3) Brown sandstone from Little Falls	1.34
(4) Shaly brown sandstone, Belleville quarries	5.74
(5) Light drab sandstone from near Plainfield, N. J	3.03
Average	3.39

These analyses show that the trap rock contains about 3.7 times as much ferric oxide as is contained in average samples of the brown sandstone of the associated sedimentary beds.[4] It is impossible to compare the mass of the trap in New Jersey with the mass of the associated sedimentary beds, but we may assume with a fair degree of probability that the masses of the rocks mentioned are to each other as the areas of their outcrops. From the geological map accompanying the Annual Report on the Geology of New Jersey for 1881 I find that the outcrops of trap occupy 225 square miles, and the outcrops of the sedimentary beds 1,245 square miles.[5] That is, the ratio of the area occupied by igneous rocks is to the area occupied by sedimentary rocks of the same system as 1 : 5.5. This rough computation seems sufficient to show that the Triassic igneous rocks do not contain as much ferric oxide in the aggregate as is contained in the sedimentary beds, which are supposed to have derived their color from them.

The facts presented above in reference to the uniformity of color of the Newark sandstones, the unaltered condition of the trap rocks, and the excess of iron in the sedimentary beds over that contained in the associated igneous rocks are true not only for New Jersey, but throughout all the Newark areas from Nova Scotia to South Carolina, and, I believe, militate strongly against the hypothesis that the clastic beds of the Newark system derived their ferric oxide from the sheets and dikes of igneous rock which traverse them.

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[1] Ann. Rept. Geol. Survey New Jersey, 1884.

[2] Geology of New Jersey, 1868, pp. 215–218.

[3] The analyses numbered 1 to 4 are by Charles Catlett, of the U. S. Geological Survey, and represent the per cent. of ferric oxide (Fe_2O_3) obtained by digesting samples of sandstone in acid, and therefore give the per cent. of ferric oxide in the cementing material of the samples. No. 5 is from the Geological Survey of New Jersey, 1868, p. 509. Other analyses are given on pages 515, 516 of the same report.

[4] Persifor Frazer has computed that there are contained in every mile of strike one chain in dip and one yard in thickness of the Newark sandstone, 6,193.44 long tons of ferric oxide. Trans. Am. Inst. Min. Eng., vol. 5, 1876–'77, p. 501.

[5] The area given above for the outcrops of the trap rock is greater than would be obtained if the surface of the country were reduced to a plain, for the reason that the edges of the trap sheets stand in relief and form monoclinal hills.

On pressing to the extreme the hypothesis proposed by Cook, it might be assumed that the sandstones and shales still existing in the Newark basins received their coloring matter from those portions of the intrusive rocks which have been eroded away; the iron having been leached out as decomposition progressed, and redeposited in the sandstones at a lower level. This extension of the hypothesis meets the objection that the proportion of trap to sedimentary beds in that portion of the formation which has been removed by erosion was probably about the same as in the terranes remaining, and that the iron derived from the trap would have been insufficient to color the clastic beds with which it was intimately associated. Again, it might be assumed that the sheets and dikes of trap now remaining led up to vast overflows of igneous rock which have been entirely removed, and that the disintegration of this supposed lava sheet supplied the ferric oxide of the clastic beds beneath. These extensions of the hypothesis, however, are so fanciful, that they need not be considered at the present time.

In the last line of the quotation given on page 50 the statement is made that the coloring substance of the Newark rocks appears to have been supplied at the time of their deposition. This manifestly could not have been the case had the coloring matter been derived from the leaching of the trap rocks, as suggested in previous parts of the same quotation, for the reason that the trap is largely intrusive, and was forced in among the sedimentary beds after their deposition and consolidation.

In discussing the origin of the characteristic color of the rocks of the Newark system in New Jersey, J. S. Newberry[1] states that—

> The New Jersey highlands, as well as other portions of the Blue Ridge belt, are known to contain great quantities of iron ore, and the erosion of the gneiss which forms this belt must necessarily result in the distribution of a large amount of iron. Hence it is not surprising that the shales and sandstones all contain enough of this element to give them a red or reddish color whenever it is in the form of the anhydrous peroxide. The fact that it is generally in this condition, and therefore the rock is red, proves that it contained little or no organic matter when deposited, for whenever decaying organic matter is present in any considerable quantity it reduces the peroxide of iron to protoxide, and makes the color, so far as influenced by the salts of iron, gray, green, or blue. Where the organic matter is in very large quantity, it imparts the characteristic color of carbon, and makes the shale of limestone which contains it black.

The hypothesis that rocks are red because they do not contain organic matter has been stated with some minuteness by H. Newton,[2] in explanation of the origin of the color of the Red Beds of the Rocky Mountain region. I quote his discussion in full:

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[1] *Mon. U. S. Geol. Survey* No. 14, 1888, pp. 7, 8.

[2] *Rept. on the Geol.* and Resources of the Black Hills of Dakota, Washington, 1880, p. *138, 139.*

> The large percentage of peroxide of iron in the Red Beds, to which they owe their bright red color, bears an interesting relation to the absence of fossils. The material of which sediments are formed is derived by the various processes of denudation from rocks of older land surfaces. Whatever iron they contain is dissolved from the land and transported in the condition of protoxide or some protosalt, such as the carbonate, and the process is facilitated by the presence of carbonic acid in the water. Now iron occurs in these older rocks as peroxide and protoxide, the former of which is soluble and the latter insoluble in water. The peroxide, however, by the action of organic matter, such as is held in solution by boggy waters, may be deprived of a portion of its oxygen and converted into protoxide, and thus rendered soluble. If the iron-bearing water is confined, as in a shallow basin, and exposed long to the action of the atmosphere, the protoxide of iron absorbs oxygen, and is precipitated as the insoluble red peroxide of iron. If, however, plant or animal life be present in sufficient quantity, this oxidation is prevented. In case but little foreign material—clay or sand—has been brought by the waters, the deposit will be an iron ore; in the absence of organic matter, the peroxide or brown hematite; or in its presence, the protocarbonate, such as the iron-ore beds of the Coal Measures. But in case large quantities of foreign material are deposited from the waters at the same time, there will be produced, in the absence of life, a brown or red clay or sandstone, and in its presence a white or light-colored formation containing the iron as a protoxide. This question of the removal and deposition of iron has been ably elucidated by Dr. Newberry and others, and Dr. Hunt "can hardly conceive of an accumulation of iron, copper, lead, silver, or gold in the production of which animal or vegetable life has not either directly or indirectly been necessary." The point to be established by this seeming digression is this, that, reasoning from the condition in which the iron is found in the Red Beds, we must conclude that there could have been little or no life, animal or vegetable, in the waters from which they were deposited. The conclusion is strengthened by the fact of the presence of large quantities of gypsum, which has been derived from the evaporation of saline waters. The degree of saline concentration which the precipitation of gypsum indicates would be highly inimical to life.

That the chemical processes mentioned in this hypothesis are active in the segregation of ores there seems abundant evidence, but that the color of great terranes can thus be accounted for is not so definite.

This hypothesis implies that red rocks are the deposits of inclosed basins, which it is known is by no means the universal rule. It also suggests that red deposits should now be accumulating in the inclosed lakes of arid regions. This we know is not the case. Not a single instance of the deposition of iron-stained beds in the inclosed lakes of this country has been observed, although a number of cases are known where gypsum and other salts are being deposited. The lakes in which these precipitates are being thrown down are in a desert region and are free from notable quantities of organic matter.

There are striking exceptions, too, to the frequent statement that red rocks are destitute of fossils. Certain sandstones near Taylorsville, Plumas County, Cal., which are even brighter red than the normal sandstones of the Red Beds or of the Newark system, are rich in a great variety of marine invertebrates.

A. H. Green,[1] in a lecture on the geology of coal, remarks that the Middle and Lower Coal Measures and the Millstone Grit of England are blue and gray when protected from the action of the air, but of various shades of brown and yellow at or near the surface. On the other hand, the prevailing colors of the Upper Coal Measure are red, purple, and mottled red and green. The color of the red rocks "is caused by every grain being coated by a thin skin of ferric oxide." This coating of coloring matter is supposed to have been deposited on the grains of sand from the waters of the inclosed lakes in which it accumulated, which were "red as blood, owing to the presence in large quantity of finely divided ferric oxide." The source of the ferric oxide is thought by Green to have been of volcanic origin, and to have been derived from the decomposition of ferric chloride arising from neighboring volcanoes. In reference to this hypothesis A. A. Julien observes:[2]

> Especially is there no need of ascribing to a volcanic sublimate the source of the ferric oxide. The western prolongation of the Archean rocks of the Scandinavian peninsula, referred to by this author, probably covered by heavy vegetation and swamps, must have afforded an ample area and volume of ferruginous materials for the solvent action of humus acids on a vast scale and through a long period, sufficient to have supplied the ochreous cement of the sandstones in the Carboniferous seas.

The hypothesis suggested by Green and supplemented by Julien falls in the same category as the hypotheses proposed by Ramsay, Newton, and Newberry, and is open to the same objections.

The red color frequently seen on the surface of many outcrops, which are light-colored when unweathered, is supposed by T. B. Comstock[3] to have resulted from the action of ozone in the atmosphere on the iron contained in the rocks in small quantities.

The red coloring matter of the Newark and other similar rocks has undoubtedly been assumed by many to have resulted from the infiltration of ocherous matter after the fragmental grains of which they are composed were deposited. Microscopic examination of thin sections of the rocks in question, however, does not sustain this suggestion. As shown by the microscope, the sand grains are seldom in direct contact, but are separated by the incrustations surrounding them, which would not be the case had the red matter been brought in by infiltration. The spaces between the sand grains are usually completely filled with ocherous matter, and it is possible that a part of this at least is due to infiltration or to a re-arrangement of the finer material of the deposit; the same result would be expected, however, from the deposition of the finely divided ocherous material at the time the sand grains were accumulated.

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[1] Coal, its history and uses, by Professors Green, Miall, Thorpe, Rücker, and Marshall, London, 1878 pp. 62–66.

[2] On the geological action of the humus acid, Proc. Am. Assoc. Adv. Sci., 28th (Saratoga Springs) meeting, 1879, pp. 404. 405.

[3] *Geological report.* In report upon the reconnaissance of northwestern Wyoming, *by W. A. Jones, Washington*, 1874, 8vo., p. 178.

The great thickness of the strata through which the coloring matter is sometimes uniformly disseminated can not be accounted for on the hypothesis of secondary infiltration. Besides, the iron-stained rocks are frequently interbedded with gray and often with white sandstones, showing that the coloring matter was deposited at the same time as the sand grains with which it is so intimately associated and not subsequently introduced. The interstratification of colored and uncolored layers is also opposed to the hypothesis that widely spread change in the color of rocks has been produced by igneous intrusion.

EXCEPTIONS.

The considerations presented in the present paper in explanation of the color of the iron-stained rocks manifestly do not apply to sandstones and allied rocks formed principally of feldspar and quartz in which the color is inherent in the composing minerals.

Again, it is well known from the explorations of the *Challenger* expedition and of the various surveys made by the U. S. Fish Commission, that red clay is found in the abyssal portions of the ocean. This clay, as shown by C. Wyville Thomson and others, is a subaqueous residual deposit, formed in part of the insoluble portions of the shells of mollusks and of microscopic organisms, which descend principally from the surface of the ocean and are partially dissolved during their subsidence. It is also composed in part of pumiceous particles, which have been drifted to great distances on the surface of the sea, together with volcanic, aërial, and cosmic dust. The material from all these sources has been long exposed to the solvent action of sea water, so that only the comparatively insoluble residue finally accumulates on the bottom in the deeper parts of the ocean. Owing to the extreme slowness with which ordinary sedimentation takes place in those portions of the ocean most remote from land, the residual deposits mentioned above are allowed to accumulate until they form homogeneous layers of broad extent and perhaps of great thickness. Although the red clay resulting from the solution of limestones, etc., under subaërial conditions, and the red clay resulting from the subaqueous decay of pelagic shells, dust, etc., are similar, yet, owing to their different associations, one is not likely to be confounded with the other. As the history of the formation of the oceanic clay is foreign to the purpose of the present paper, further notice of it is omitted.

Other exceptions might be cited, as when the colors of rocks are altered by volcanic heat or by the burning of carbonaceous strata. Fresh lavas and lapilli deposits are frequently brown and red, and would make sedimentary beds of the same colors if deposited in water. Such *cases usually* explain themselves, however, and need not be discussed *at the present time.*

III.—RÉSUMÉ.

The formation of red deposits from the débris of rocks that are not red, but contain iron in the hornblende, mica, chlorite, magnetite, garnets, pyrites, and other minerals of which they are composed, evidently necessitates that the minerals holding the iron should be decomposed and the iron oxidized. This process we now find in operation over large portions of the earth's surface in the formation of residual deposits, of which the terra rossa of Europe, the laterite of India, the red earth of Bermuda and the residual clays of the southern Appalachian region are the best known examples. The residual deposits resulting from the subaërial decay of crystalline rocks agree both in chemical composition and in the manner in which the grains of sand are incrusted with ferric oxide, with the sandstones of the Newark system, and with other formations of a similar lithological character. Moreover, the residual deposits of the Southern States are assorted and deposited by streams without losing the ferric oxide which incrusts the grains, thus showing that they are capable of forming iron-stained sandstones and shales.

The hypothesis advanced in view of these facts is, that the sands forming the sandstones of the Newark system and other similar formations received their incrustations of ferric oxide during the subaërial decay of the rock from which they were derived.

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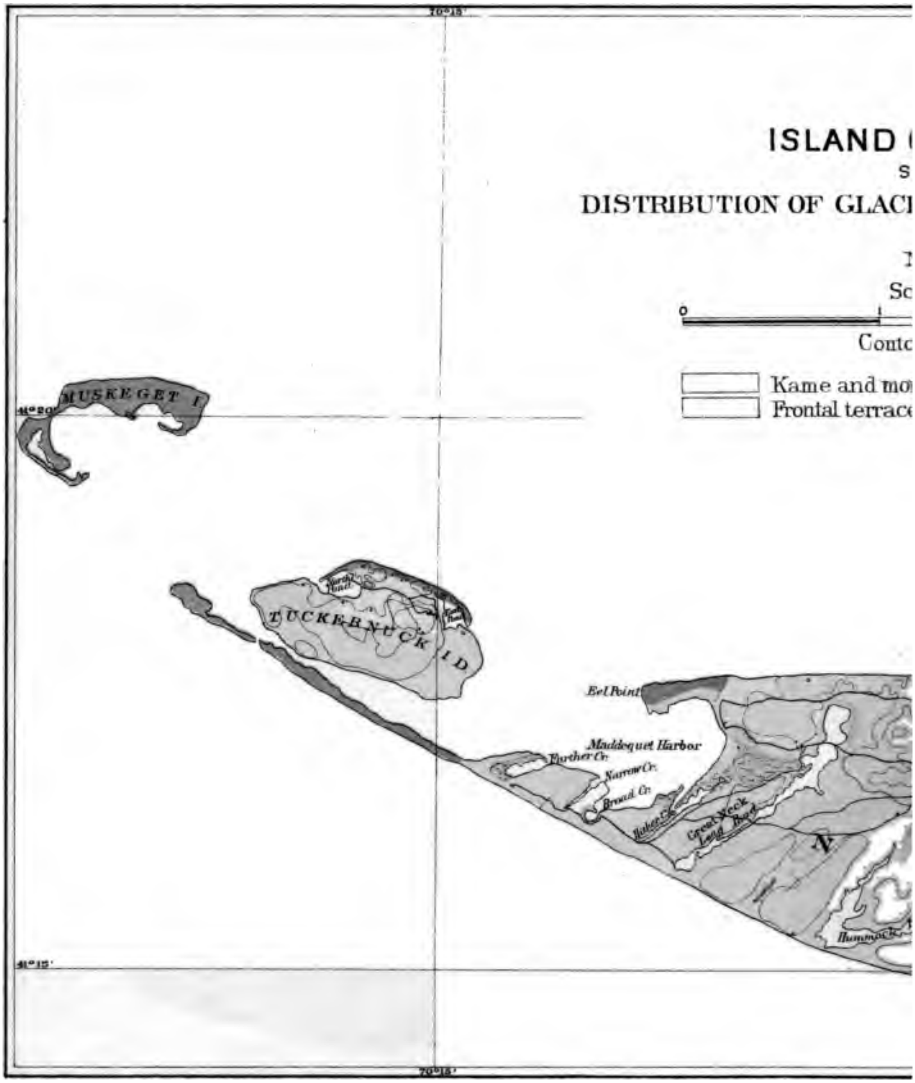

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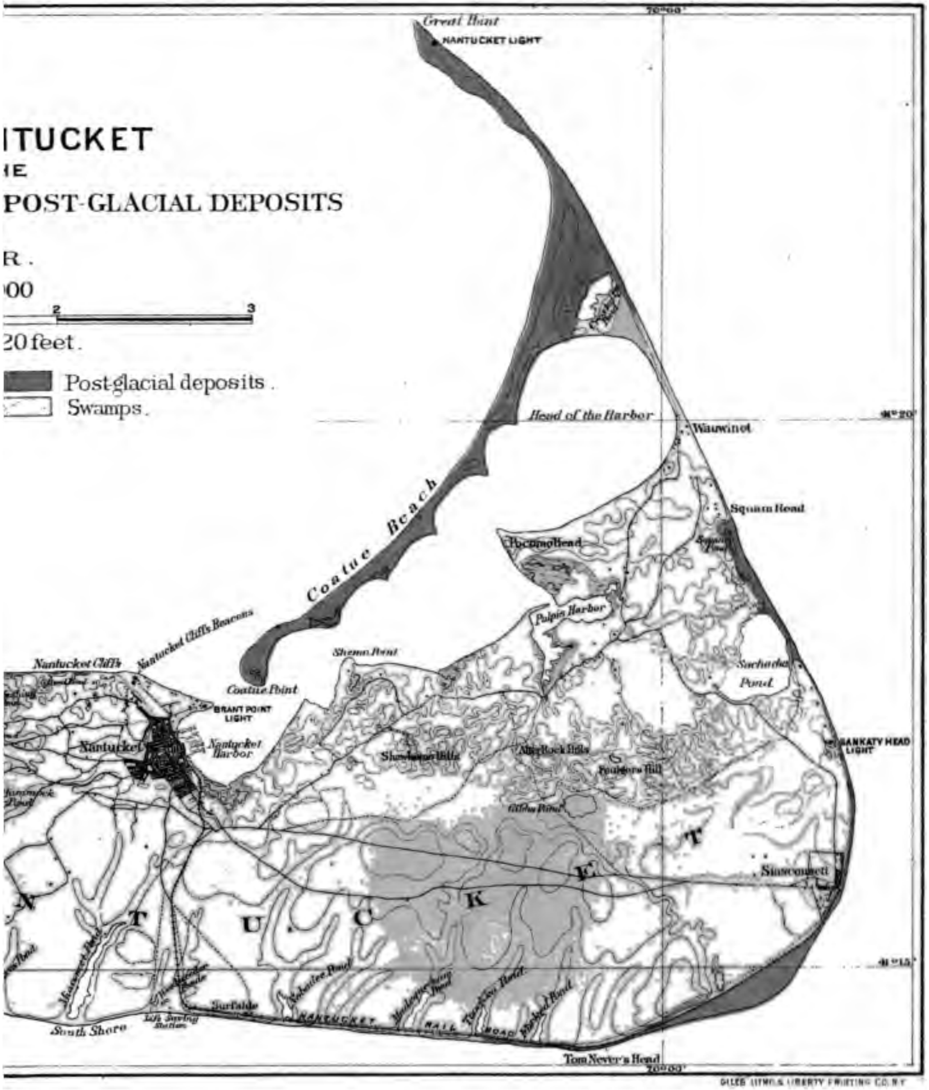

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THE
GEOLOGY OF NANTUCKET

BY

NATHANIEL SOUTHGATE SHALER

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LETTER OF TRANSMITTAL.

U. S. GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
Cambridge, Mass., April 26, 1888.

SIR: I have the honor to transmit herewith a report on the geology of the island of Nantucket. This report embodies a portion of the work which I have done in connection with the general study of the Atlantic coast line. Although part of a much more extended inquiry, it seems well to publish the results contained in this memoir in advance of my general report for the reason that the region constitutes a distinctly bounded field and also because the problems considered in this report have an important bearing on work which is in the hands of other divisions of the Survey.

Very respectfully, your obedient servant,
N. S. SHALER,
Geologist in charge.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

GEOLOGY OF THE ISLAND OF NANTUCKET.

By Nathaniel S. Shaler.

PREFATORY NOTE.

The island of Nantucket occupies a position which makes its structure of great interest to the geologist. It lies near the extreme southeastern point of a great salient of lands and shoals forming the southern front of New England. This district, unlike the main-land of New England, exposes none of the older rocks; it is composed of sands, gravels, and clays which were brought into their present position during or immediately before the last Glacial Period. It should be noted that the island of Nantucket is but a small fragment of a vast sheet of this glacially transported matter. The greater part of Plymouth County, Mass., the whole of Cape Cod, the larger portion of Martha's Vineyard, and the whole of Long Island, with all the many islands and islets at its eastern extremity, are the dissevered remains of a great shelf formed of the débris brought to its present position by the glacial ice and by the streams of water which flowed beneath it.

Owing to its extreme southeastern position the island of Nantucket affords evidence concerning the history of the ice sheet which can not be obtained at any other point on the coast: it has, therefore, seemed worthy of the detailed studies which will be presented in this report.

The general form and structure of the island will be first considered: after that the relations of the area to the other parts of the district will be set forth.

GENERAL FORM OF NANTUCKET.

As will be seen from the map that accompanies this report (Plate I), the form of the island of Nantucket is rudely crescentic; its shape may be compared to that of the implement known as a bill-hook. Its extreme length in an east and west line is about eleven miles. The westernmost mile of this length is formed by a sandspit which is constantly varying in its extension. At present this sandspit has only about one-third of the length indicated on the map, so that the permanent part of the island may be estimated at ten miles in length. The north and south width of the island does not at any point exceed seven miles, but the northern three miles of this width included in the spit of Great Head are made up of blown sands and detritus carried to its position by the currents of the sea; so that the part of the area which was formed during the glacial period does not exceed four miles in width. This measurement is also variable, for Great Head has lost 1,400 feet in length since 1784.[1]

The surface of the island, though varied, has a narrow range of height, the loftiest point being about ninety feet above the level of the sea. Through its central part there extends a series of low but extremely numerous and irregularly shaped hills of glacial drift. On the western part of the island this hill belt comes to the shore which forms a boundary of the island; on the eastern part the hills are cut transversely by the coast, forming the bluffs which face the sea from Siasconset to Squam Head. On the southern half of the island this line of low drift hills declines into a plain of sand, which extends with gentle slope from the base of the hills to the sea, terminating in a series of low bluffs rarely exceeding twenty feet in height.

The coast line of the island is cast in a set of very gentle curves united by lines of straight shore. On the southern and eastern faces the shores are either straight or very gently convex; on the northern coast the sea line exhibits no convex curves. This conforms to the general rule that long gravelly shores which face the open sea have, prevailingly, a straight or slightly convex form. (See Pl. IX.)

The details of the shore line of this island present many interesting features, most of which can be noted in connection with the geological structure of the island, but some of them may best be considered in this general sketch of its topography. The most remarkable of these topographic peculiarities is that which is commonly known as Coatue, including the harbor and the beach of that name, and the promontory of Great Head.

This remarkable district exhibits a number of very singular features. The most notable of these are Coatue Bay and the sand beach which separates it from the sound on the north. Coatue Bay has the most puzzling configuration of bottom and of shores of any inlet on the North American coast. The bottom is divided into two great basins and a third one of lesser extent. In these basins the sea-floor slopes gently from the shores to considerable depths, the two greater easternmost basins having about twenty feet of water at low tide, while the barrier between them has then only about three feet of water upon it.

The configuration of the shores is even more peculiar than that of the bottom. On the south the boundary of the bay is quite irregular, being decidedly more indented than the general outer face of the island, for the evident reason that it has been protected by Coatue Beach from the action of strong waves. On the north shore of Coatue Bay the low dune-covered Coatue peninsula has six small crescent-shaped bays, of which five are very distinct in their outlines and of about the same size. These bays are each a little less than a mile wide, and the base of their curves is about two hundred yards from the line which connects their promontories. From each promontory there extends for a distance of 200 yards or more out into the bay a sandspit which is not delineated on the general map, but which, if represented, would add much to the peculiarity of their aspect. They are diagrammatically indicated in the appended sketch (Fig. 1). The cause of these peculiar projections is not plain. They are possibly due in some way to the action of the tidal currents, which sweep up the bay with much speed and move the fine-grained sands with considerable ease. From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shore between these salients and accumulate the sand on the spits.

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[1] See Monomoy and its shoals, Henry Mitchell: Annual Reports of Harbor and *Land Commissioner of* Massachusetts, 1837 to 1842.

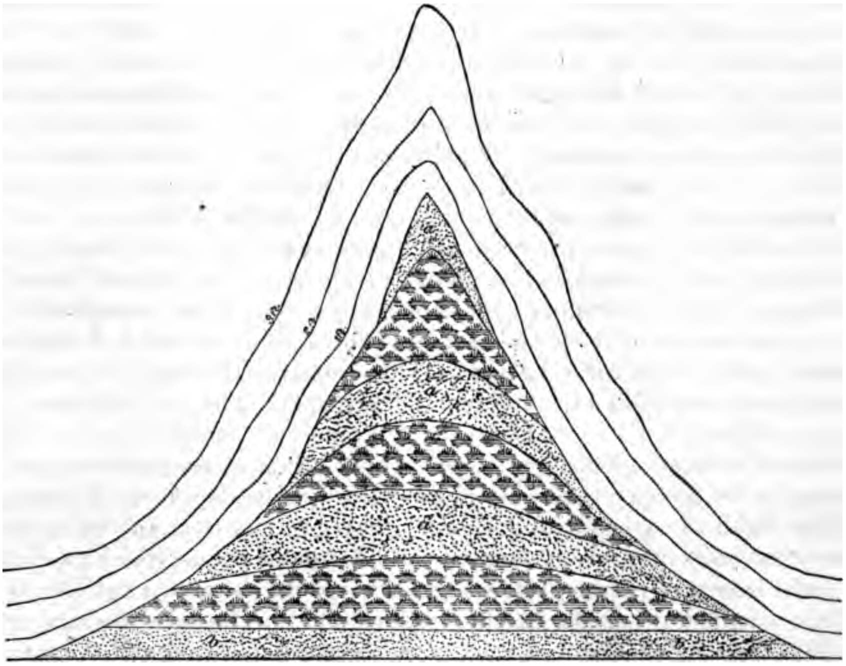


FIG. 1. Diagrammatic horizontal section of small spit on Coatue Beach.
a, *a*, *a*, successive beaches; *b*, *b*, promontory.

It is evident on inspection that the process which brought about the construction of these bays is still in operation. On each of the little headlands separating the basins there are traces of very recent, if not still active, building out of the point toward deeper water. On three of the points there are small salt-water ponds placed as indicated in the diagram. These pools are inclosed behind a low beach wall, formed during some great storm by the waves of the bay in which they lie. The lagoons are not clearly traceable on the other points, but they all have the general form and structure shown in the diagram.

Coatue Beach, on the southern boundary of which lie the above-described bays, is in itself a remarkable bit of shore topography. It clearly belongs to the class of barrier beaches such as are originated along coasts by the breaking of the waves in shallow water. It is evident that this beach has grown slowly and by successive and variable accretions; even in its narrow width we can trace a number of low walls which mark the line of the sea at various stages in the progress of its growth. The whole of these sands have been thrown up from the bottom of Nantucket Bay (Fig. 2). When we come to consider the successive changes of level of this island we shall find that this beach affords us evidence of some value as to the nature of these movements.

The long sand strip known as Great Head is the third element in this peculiar topography. This promontory is essentially like many others on the sandy shores of our coast. It will be observed that while the elevated and older portion of this spit trends in a northwest and southeast direction, the submerged and more recently formed portion, which is covered even at low water, has an axis nearly at right angles to this trend, and also that this under-sea part is much more irregular than the emerged portion. This sudden change in the direction of the spit may very properly lead us to the conclusion that there has been considerable change in the course of the currents which have swept these shores in recent time, a change dependent on the alteration in the shape of the lands, which has in turn affected the action of the sea. The structure and history of this point will be hereafter considered.

In connection with the shore line of Nantucket, we should notice the fresh-water system of the island. This is extremely peculiar. There is not a single well-defined stream on Nantucket. The only approach to brooks are a few obscure channels between ponds where the water has, except in times of flood, a feeble current. This absence of streams is due to the great porosity of the sand and gravel deposits. The fresh and brackish water ponds are quite numerous. They are divisible into two tolerably distinct classes, viz, the subcircular ponds, which are scattered irregularly through the sand-hills, and which range in size from a few score feet to a half a mile in diameter, and the elongate ponds, which lie in the long shallow troughs leading from the south slope of the range of sand-hills down to the Atlantic shore. With the single exception of Croskaty Pond, which lies on the northern part of the island, these elongated ponds are limited to the southern shore. With trifling exceptions, these elongated ponds have axes which trend in the direction of about N. 30° E. They are larger in the western than in the eastern half of the island. These singularities of position depend upon their relation to the remarkable shallow valleys in which they lie. As will be seen in the later portion of this paper, their peculiar form and arrangement have been given them by the conditions of the Glacial Period.

The reader should note the fact that, while the northern shore of Nantucket extending west from the harbor of that name to Matacut Harbor, presents a remarkably straight and unbroken face to the sea, the southern border of Coatue Bay or Sound is very deeply indented. The straight shore is the normal form of the coast line, where the materials exposed to erosion are of a very uniform nature, which is assaulted by waves of considerable power, such as break upon this coast in times of storm. The indented shore has the form which a coast composed of such materials assumes when it is not exposed to the action of strong current and powerful waves, as the inner shore of Coatue Bay must have been exposed before the present beach was constructed.

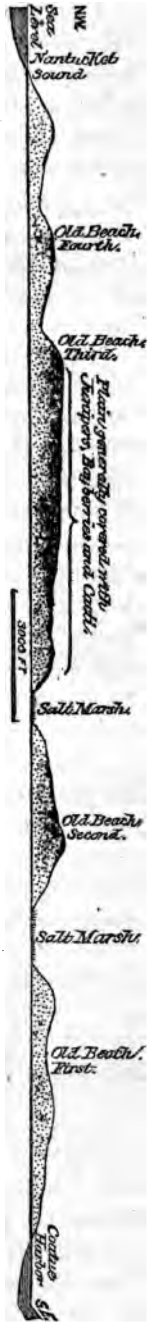


FIG. 2. Diagrammatic section through Coatue Beach.

These considerations of the existing and more evident geographical features of Nantucket fairly present to us the problems of a geological nature which we shall have to consider in our study of the island. We shall first endeavor to determine the geological structure of the several parts of this area and the conditions under which the beds were accumulated; next we shall try to ascertain the changes which have taken place through the action of the waves and currents of the sea; and finally we shall consider the light which the structure of this island may throw on the geological history of the shore land, of which it forms a part.

GENERAL GEOLOGICAL STRUCTURE.

The lowest deposit exposed on the island consists of a bed of clay, generally blue and compact, scantily intermingled with pebbles and sand, the whole forming a deposit which is probably to be classed as till or bowlder clay. The mass is apparently though obscurely stratified. Its pebbles are occasionally scratched. Throughout they have the angular or faceted character common to glacial pebbles. When considerable sections are exposed, as is the case at two or three points, the upper deposit for fifteen or twenty feet is seen to be altered to a yellowish or grayish color, while the mass below is of the characteristic blue color of such clays. In general aspect, as well as in details of structure, this mass is indistinguishable from the ordinary till of the mainland.

except that its pebbles are always of smaller size, rarely exceeding two or three inches in diameter, and that it is clayey and less compact than the similar deposits of more northern regions. At one point on the northern shore of the island, about a mile west of the harbor, the till passes upward into a fine-grained blue clay, this overlying deposit being at least ten feet in thickness; but generally the clay retains its admixture of pebbles to the upper surface. It is best seen at Squam Head (Fig. 3), on the north shore, near the pumping station of the water-works (Fig. 4), and in the village of Nantucket (Fig. 5).

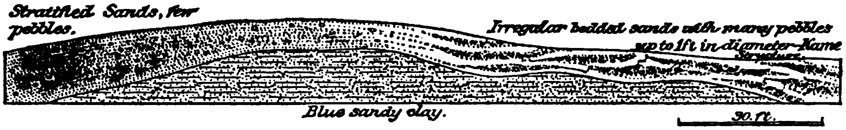

Stratified Sands, few pebbles.
Irregular bedded sands with many pebbles up to 1ft in diameter-Kame Structure.
Blue sandy clay.
30 ft.

FIG. 3. Generalized section of Squam Head.

The underlying till deposit does not rise above the level of the sea save in a small portion of the surface of the island. Along the larger part of the shore its upper surface is certainly below the level of the sea. The highest point at which it has been seen is in a clay pit worked for road material in the western part of the village of Nantucket. At this point its upper surface is about thirty feet above the level of the sea. The next highest point where it has been observed is at Squam Head, on the eastern shore, where its surface is about twelve feet above the sea level. It is certain that at many other points in the central part of the island, as for instance in the promontory between the arms of Hummock Pond, it attains equal elevation; but this interior surface is so masked by gravelly drift, that it is not possible to determine its position with accuracy.

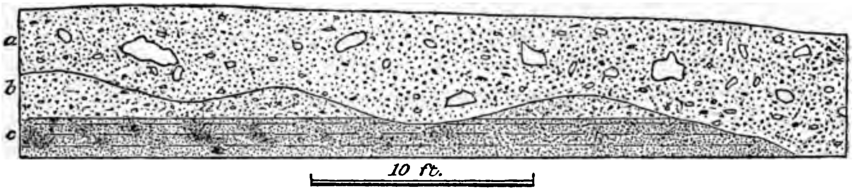


FIG. 4. Section at Weewocket.
a, till-like deposit; *b*, pebbly sand; *c*, blue clayey sand.

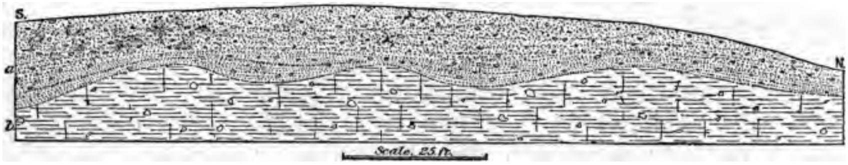
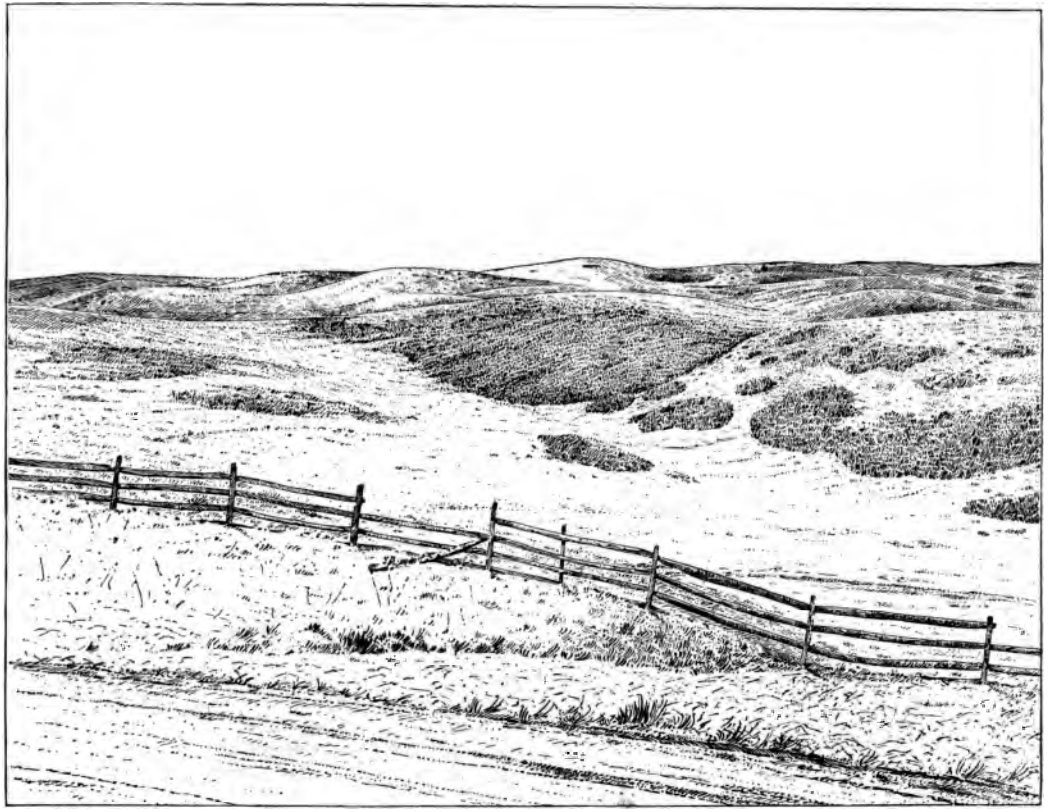


FIG. 5. Section on border of Lily Pond.
a, kame sands and gravels; *b*, bluish yellow till, very much jointed, with a few angular pebbles.

The surface of this till appears to be cast into very broad and low *arch-like elevations*, with lesser hummocks upon them, the principal



ASPECT OF KAME MORAINE ON THE NORTHERN BORDER, NEAR SHEMO POINT.

axes of which extend in a north and south direction. At least three of these wide backed ridges project themselves above the level of the sea. One of these, perhaps the most extensive, rises from Coatue Bay, on the shore east of Pocomo Head, and underlies the lowlands about Polpis Harbor. It is traceable on both sides of that harbor, having at this point a width above the water line of about one mile. On the shores of Coatue Bay it does not at any point rise more than five or six feet above the water level. Half a mile south of Polpis Harbor the ridge may have an elevation of fifteen or twenty feet, and here it becomes completely masked by the gravel deposits. Its effect, here or elsewhere, is marked in the better quality of the soil, which shows itself in the gravelly beds as well as in the clay itself, for a certain amount of the underlying clay deposit has been mingled with the coarser detrital material, making the soil better suited for agriculture. It also affords several small springs where it intercepts the waters which sink through the gravel.

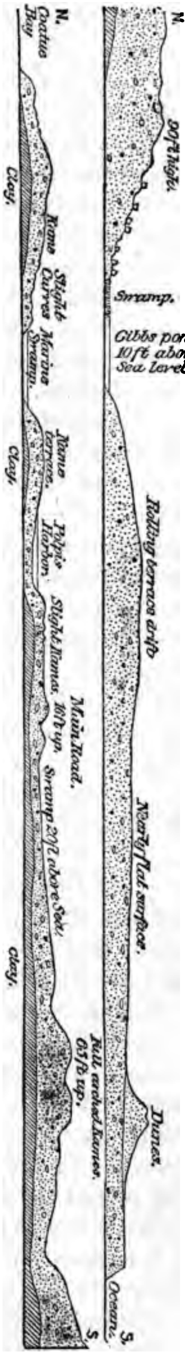


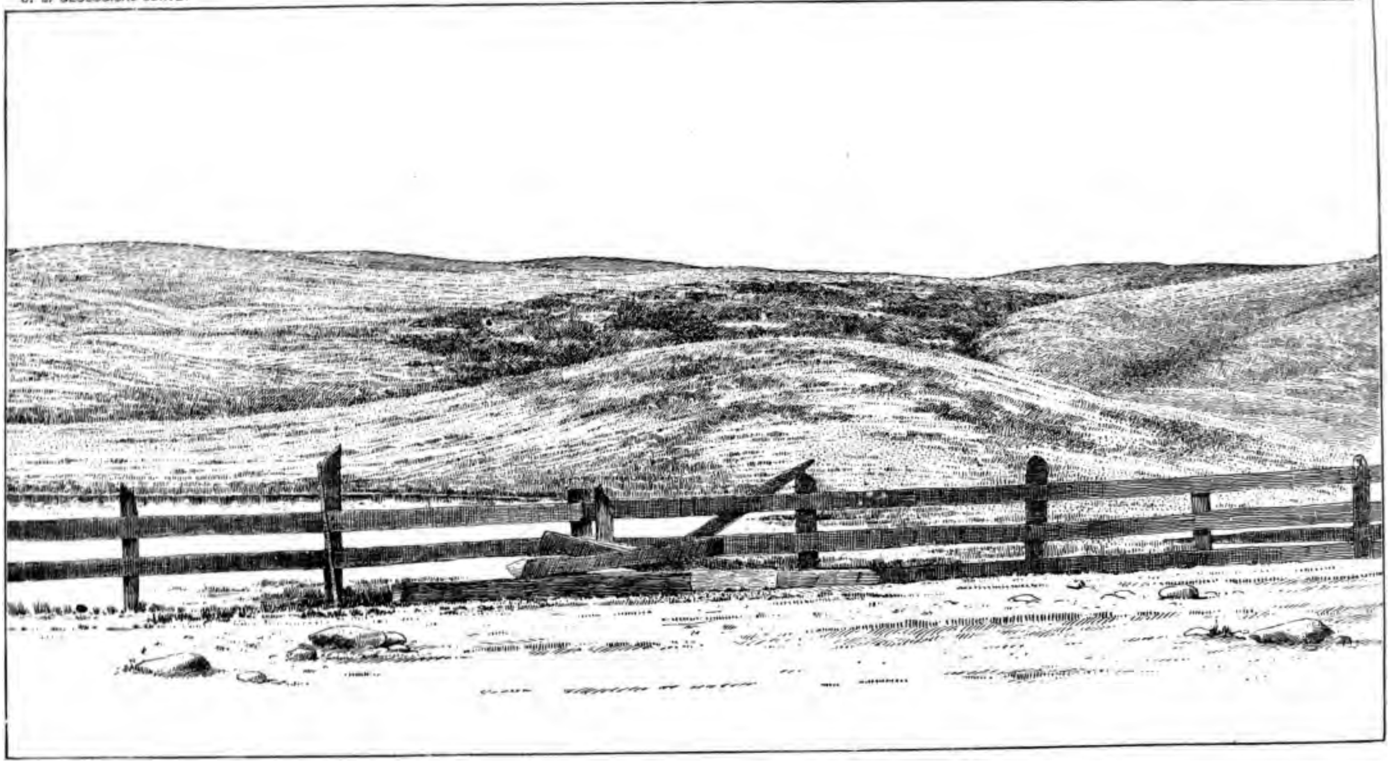
FIG. 6. Section from Coatue Bay to the ocean.

In the central part of the island there is another of these undulations of the till extending through the village of Nantucket (Fig. 5). The exposures of the clay on the north shore and in the western border of the village are upon the ridge. It may be a continuation of this ridge or it may be a separate undulation which appears in the low arched promontory between the two great branches of Hummock Pond. There is probably a similar arch of the till below the central part of the island of Tuckernuck. This was not actually seen, but has been inferred from the character of the soil on that island. There is probably yet another undulation which brings the till twenty or thirty feet above the level of the sea, at a point about a mile and a half west of Siasconset; here, too, the evidence is derived from the character of the soil and the nature of the bottoms in the low valleys, and is also indicated by the appearance of water in scanty springs. There are probably yet other points where the till rises above the sea level, but is hidden by the prevailing deep coating of the pebbly stratified drift. The diagrammatic section (Fig. 6) will give a general idea of the relations of the underlying till to the sea level and to the overlying deposits of the stratified drift.

The undulating form of this underlying clay, the generally distinct boundary of its upper surface, the apparent elongation of the arches in the ridges in a north and south direction, all serve to indicate that the mass has been worn by the glacial ice since the time when it was deposited. This view is supported, as we shall hereafter see, by the character of the deposits overlying it.

Immediately above the undulating surface of the lower clay lies a mass of more or less stratified sand, which the student of glacial phenomena at once recognizes as, in part at least, belonging to that division of the drift known as kames and the terraces which commonly accompany them. The contour of the surface is of the most varied nature, and can not well be described to any one unfamiliar with this class of glacial accumulations. A tolerable idea of its extreme peculiarities may be gained from the appended diagram, which shows sections through certain parts of this surface. Most commonly it consists of a huddle of low hills never exceeding twenty feet in height, and with extremely irregular outlines. Generally they are more or less conical in figure, often elongated in an east or west direction to a length of from one to three thousand feet. Usually they are crowded together so that their bases are adjacent, but at some points they stand in an isolated position on the southern sand plain. Where they are the most crowded they have the steepest slope, which often rises to an angle of from 20° to 30° of declivity. Even where the belts are not elongated, they are often so arranged that their summits have an east and west alignment. Between the ridges there are often considerable trough-like valleys. In these valleys, which at many points appear to extend downward to or near the underlying till, there are occasional ponds or swamp grounds, which have evidently been sheets of water, but have been closed by the growth of peaty matter. Where they remain as pools, they are generally shallow, not exceeding twenty feet in depth and usually of circular outline. (See Pls. II, III, and IV.)

Where the hills are steepest they usually are very stony, large angular blocks being scattered over their surfaces. In such cases they clearly belong to the class of frontal moraines. Bowlders were once far more numerous than at present, for the reason that they have been extensively gathered during the last two centuries for masonry constructions, cellars, wharves, and retaining-walls. Some hundreds of thousands of these are now built into the edifices of the island. In many places the surface of the ground is dotted over with the pits from which the stones have been removed. The entire absence of other building stones on Nantucket, the scarcity of good brick clay, and the cost of fuel for burning bricks have made it necessary to resort to these erratics for building materials. The result is, that this district has been more *thoroughly stripped* of its bowlders than any other known to me.



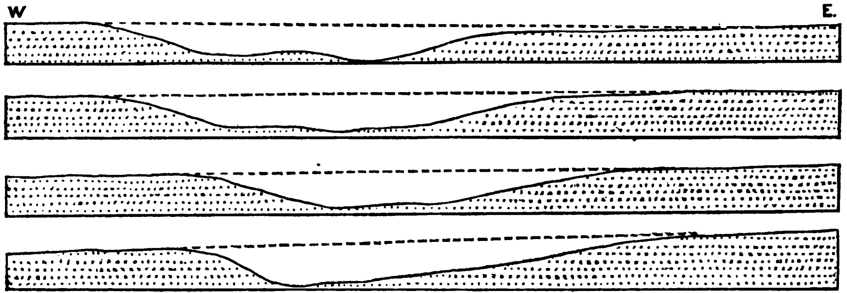
KAME VALLEY, WITH DOME-SHAPED HILL, ON NORTH ROAD, NEAR SHEMO POINT, LOOKING SOUTH.

As before noticed, this belt of sand and gravel hills is limited to the central and northern portions of Nantucket; at no point does it attain the southern shore. The hills are relatively low on the north shore; they increase in height as we go southward toward the center of the island, and on the south they fall away suddenly into a slightly rolling sand plain, which gently descends to the Atlantic shore. Near the foot of the hills this plain is much more rolling than it becomes at a little distance to the south; at most points the section from north to south shows a somewhat gradual passage from the base of the hills to a tolerably level surface near the sea.

The distribution of the sand hills within the field they occupy is not entirely regular; there are certain broad spaces where they do not occur. One of these is occupied in part by Polpis Harbor, another of less size by Sachacha Pond. There are several others of less extent. These blank spaces are common in all moraines of this type. Here, as elsewhere, they often form considerable valleys with no outlet, the rain-water passing off through the interstices of the ground. They were probably formed by the irregular motion of the ice-front, which in its retreat abandoned considerable parts of the area with such suddenness that no morainal matter was deposited upon it. If I am right in my supposition that these kame moraines were deposited at a considerable depth beneath the sea, there is a possibility that these low spaces were formed by the separation of icebergs at the front of the glacier. Such a separation of large fields of ice would suddenly change the position of the glacial front.

The most peculiar feature of the southern plains is found in certain broad channels extending from near the foot of the sand hills to the ocean shore. These channels are digitate in form; the depressions are from 200 to 800 feet in width and from 5 to 20 feet in depth; their bottoms are very flat, exhibiting no trace of a stream-bed. They slope toward the sea, with an irregular descent of about 5 feet in a mile. Their seaward extremities are in all cases below the level of the ocean and so contain more or less considerable lagoons or ponds which are barred from the ocean by a wall beach of sand through which their waters percolate and at times break their way. In some cases these lakes are very small; this is particularly the case with those on the eastern extremity of the island. West of the meridian of Nantucket village they become larger and, in the case of Hummock Pond and Long Pond, they occupy nearly the whole of the depression in which they lie. It can not be said that any of these troughs extend across the whole line of the hills, but at their head there is in some instances a nearly flat surface in which they are lost. The lake which fills the trough of Hummock Pond (see Pl. V) extends up to the foot of the hills. Its depression is continued to the north shore by a series of ponds, four in number, which are separated by low sand-hills and which indicate the persistence of the excavating action which produced the valleys across the island. The valley of

Long Pond constitutes a depression extending to within one-third of a mile of the northern shore, very nearly sundering the island, and the trough may be faintly traced across this remaining space of land. (See Fig. 7.)



Horizontal Scale, 225 = 1 in.
Vertical Scale, 69 = 1 in.

FIG. 7. Diagrammatic section across valleys in sunken plain.

At the point where these hollows originate in the sand hills, the hills are generally lower than elsewhere and have a more or less washed-away appearance. This is especially the case just east of the village of Nantucket, where two of the largest of the troughs head against the axis of the sand hills. At this point the hills themselves are in good part wanting.

West of Long Pond the troughs have been to a good extent destroyed by the invasion of the sea, but we may trace them in the valleys of Hither Creek, Broad Creek, Narrow Creek, and Further Creek to the western extremity of the island. They reappear on the island of Tuckernuck, there being two distinct trough-like furrows of this nature on that island. Counting these on Tuckernuck and reckoning all the depressions on Nantucket which can be put in this category, we have in all 23 of these remarkable depressions along this shore, or an average of about two to a mile of its east and west length. Some of these, particularly in the eastern end of Nantucket, are very small and do not distinctly extend up to the foot of the range of sand hills; still, all of them are manifestly of the same type and must be explained in the same way.[1]

We turn now to the internal structure of the sand belts and terraces. The sections through the sand belts are few in number and imperfectly reveal the structure of the mass. Where seen in section these deposits present a curious mixture of stratified and unstratified materials. In most cases the mass is throughout irregularly stratified, by far the greater portion of the materials consisting of sand and small pebbles accummulated in irregular layers. At a few points they contain, especially near their bases, materials huddled together in the manner of glacial till. It is noteworthy that wherever we find a section giving a

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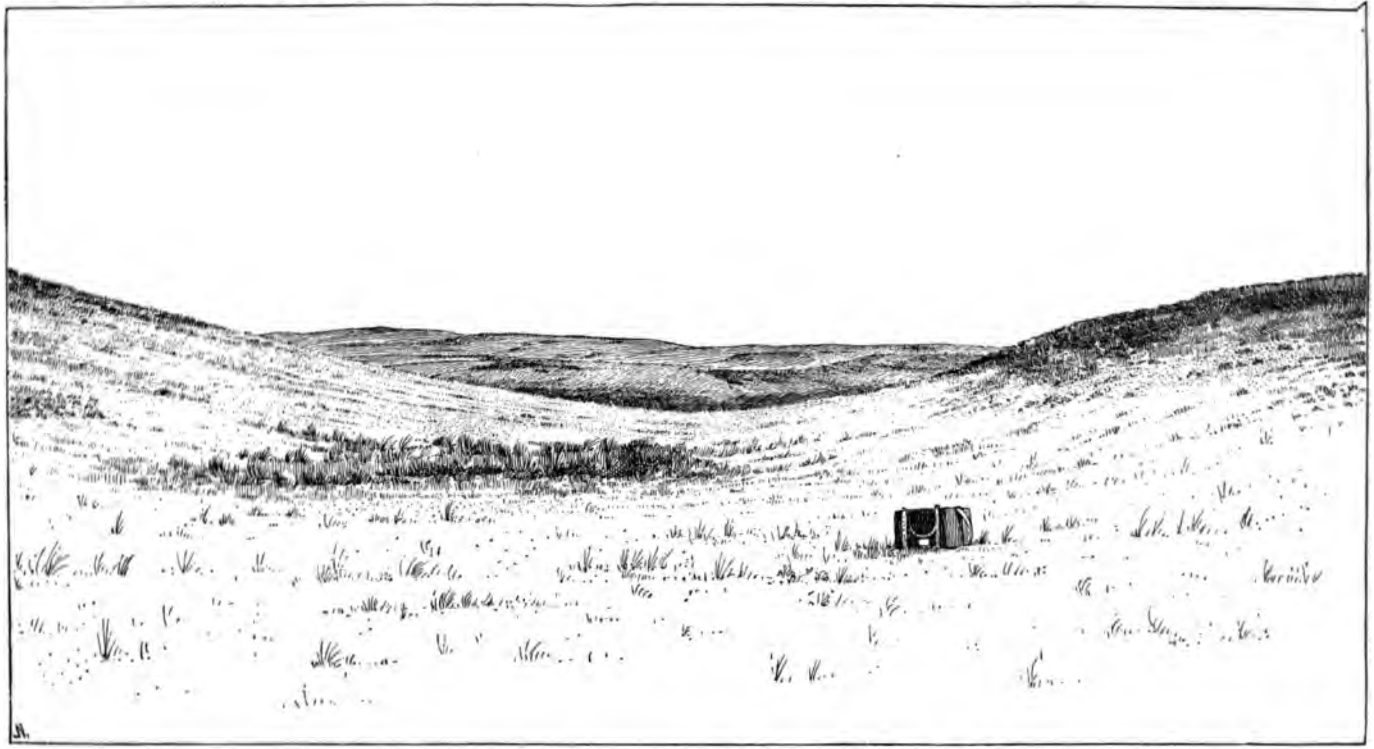
[1] A further discussion of these peculiar topographical features may be found in my report on the Island of Martha's Vineyard, Seventh Ann. Rept. U. S. Geol. Survey, *p. 314 et seq.*



TOPOGRAPHY OF KAME MORAINE IN CENTRAL DISTRICT, NEAR NORTH END OF LONG POND, LOOKING NORTH.

view of the stratified beds with the adjacent till, the gravels are found to contain a considerable mixture of clay, which appears to have been derived from the grinding up of the till upon which they lie and the mingling of the waste with the stratified kame deposits. Although there are occasionally large angular bowlders in the stratified deposits they are much less common than in the surface of the hills. On a section following the contour of the surface and ten feet below its level there will probably be not as much as one-fourth the number of large bowlders that are contained on the terraces or on the surface of the hills. This indicates that the bowlders were brought to their present positions by other agents than those which accumulated the heaps of gravel and sand. The contact of these bowlders with the surface in many cases seems to indicate that they have fallen with some violence to their present positions and have not been conveyed along the surface by glacial ice or currents of water. Here, as elsewhere in southern New England, these erratics often lie slightly embedded in the subjacent sand and gravel. It seems clear that they were brought to their present positions by floating ice. The greater number which are or were found on the surface when compared with any section of the subjacent deposits seems to indicate that the ice-rafting action continued for a considerable time after the glacier retreated from this vicinity. (See Fig. 8.)

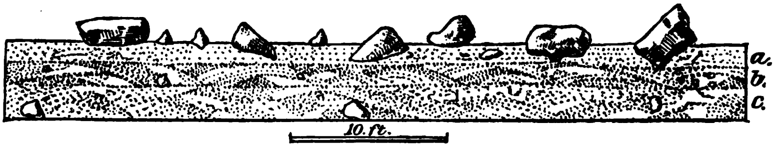


FIG. 8. Diagrammatic section—position of bowlders on glacial plain near Gibb Pond. *a*, horizontally stratified sand; *b*, somewhat irregularly bedded sand; *c*, very irregularly bedded sand.

It may be incidentally noted that if these bowlders were brought to their present positions by the ice we have from them evidence to show that this region was submerged during the accumulation of the kame deposits. Furthermore, from the fact that there are no evidences of the grounding of ice rafts on the delicately molded kames we may presume that this surface was deeply depressed beneath the sea at the time when the icebergs floated above it. In the kame hills scratched pebbles are of rare occurrence, and where found they have but faint traces of their original grooves.

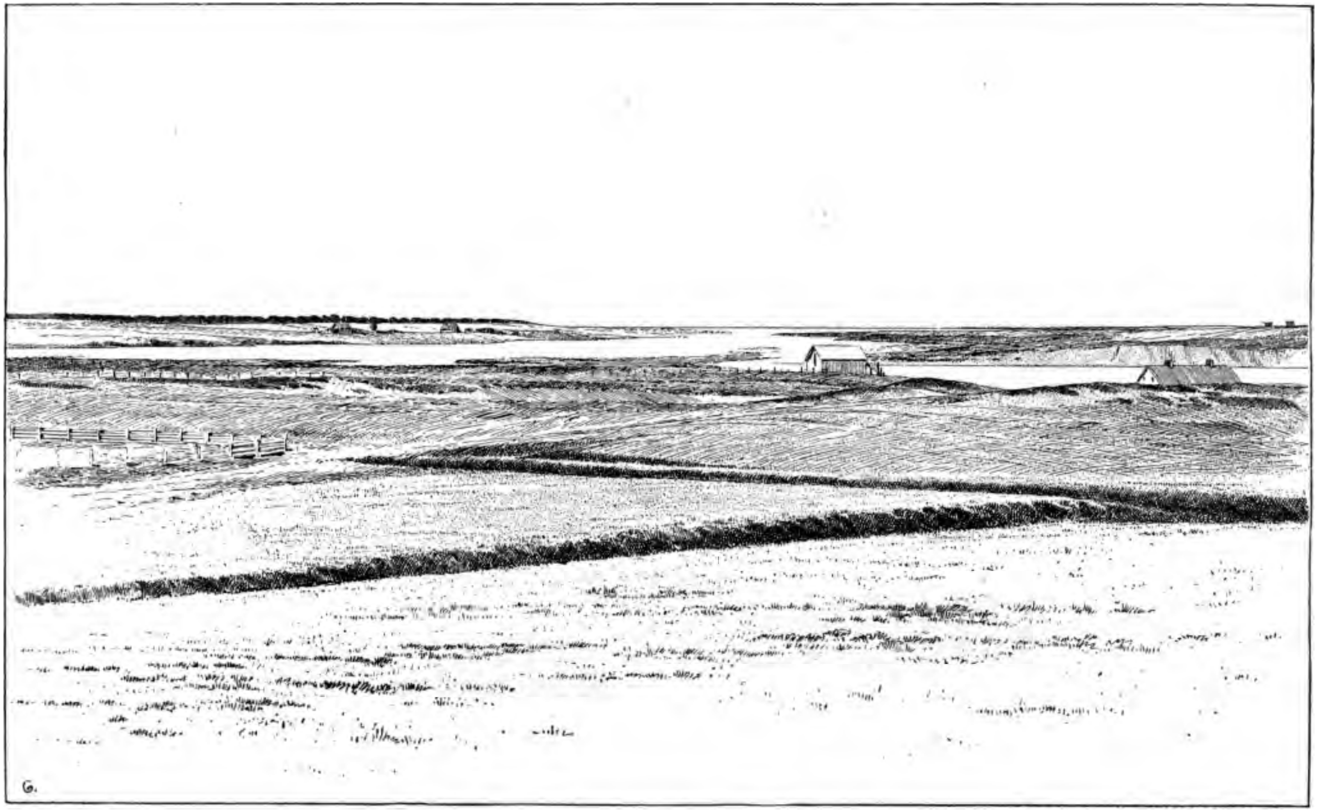
Perhaps the most noteworthy feature in these deposits of drift is the very extensive decay to which the pebbles and sand have been subjected. Some of the consequences of this decay will be noted below. In their form and structure the drift deposits differ in no distinct way from the similar accummulations found in the region a hundred miles farther north, but in their state of preservation they present important differences. The decay which has attacked the pebbles is exhibited in the following ways, viz: (1) By the interstitial decay of the stone, which manifests itself in the crumbling of many of the varieties of crystalline and fragmental rocks; (2) by the dissolved look of the surface of the rocks which resist the interstitial decay; and (3) by the development of the incipient joint planes in the pebbles, so that, though they may be but little decayed, they often split into fragments on being removed from their bed.

The interstitial decay is best shown in the pebbles of crystalline rocks where there is no magma, or base, to bind the separate crystals together; in certain varieties of syenite and in the hyperite pebbles, which not infrequently occur in some parts of the drift, this decay is most complete. It is also manifest in the numerous fragments of sandstone and in many of the conglomerate bowlders. Compared with the pebbles in the drift in the region about Fall River, Mass., these Nantucket fragments exhibit at least twice as much of this interstitial decay.

The superficial dissolving of the pebbles is a much more conspicuous and peculiar feature than the interstitial disintegration. It must be an inattentive eye which does not mark the effect of this peculiar form of decay in the erratics of the drift on this island. In appearance the pebbles subjected to this decay may be compared to crystals of rock candy partially dissolved away. The surface of the bowlders becomes very smooth, though uneven; in some cases pebbles or crystals contained in it are left as rounded projections on its face. This decay is observable in a great variety of specimens, but it is most conspicuous on the siliceous pebbles and appears to be limited to those which lie near the surface of the soil. In no case have I observed it at the depth of ten feet below, but my observations are hardly sufficient to warrant an opinion as to the depth below the surface at which it occurs.

It seems likely that this peculiar form of corrosion is due to the action of the surface waters, which, by the carbonic dioxide they obtain from the decaying vegetation, are able to effect a certain amount of solution of the more soluble stones. A trace of this action may be observed in the gravels on the southernmost part of the mainland north of Nantucket, but it is only in this island that it is a feature which quickly attracts the eye. In amount it is at least three times as great on this island as in the more northern localities. In some cases the pebbles on exposed portions of the surface show a small amount of erosion from the action of blown sand. These effects are not conspicuous and would hardly deserve mention were it not for the fact that it is worth while to discriminate between the considerable corrosion due to leaching and the inconsiderable amount effected by the erosive action of moving grains of sand.

In connection with this subject it should be noted that the bed-rocks of the mainland often exhibit a notable amount of decay which has taken place since the close of the Glacial Period. The amount of this corrosive action varies greatly according to the constitution of the rock and the extent to which it has been protected by the covering of



EAST BRANCH OF HUMMOCK POND, LOOKING SOUTH.

the drift; but when the rock has been to any considerable degree exposed to the action of the waters corrosion has generally affected it to the depth of a foot or more. This process of decay is traceable in the northern part of New England, though in that section it is relatively very slight, requiring close observation to detect it. In the region about Boston it becomes much more evident, the diabasic rocks of that vicinity having been decayed to the depth of twenty feet or more. Along the shores of Narragansett Bay the decay has penetrated less deeply, but more generally, into the rocks, none, except those which have been deeply covered by till, having entirely escaped the corrosive action. Where the bed rocks have so far suffered from this corrosion it is to be expected that the pebbles in the kame and terrace drift will be found even more extensively altered.

The third evidence of decay is that afforded by the splitting of the pebbles contained in the drift. This is a tolerably conspicuous feature in all parts of the deposits above the level of the lower till. The fractures are of two kinds: those which have taken place in pebbles as they lie, the fragments remaining connected, and those which have taken place in a remote period before the last movement to which the gravels have been subjected. This recent splitting is observable in all the glacial drift of New England. It is especially marked in the kame deposits, because the agents of decay penetrate more readily into the débris of this description than into the less porous till. On Nantucket it is, however, much more conspicuous than elsewhere, so far affecting the pebbly beds of the island that a large part of the fragments fall to pieces on exposure and many others are readily shattered by a very slight blow. The greater prevalence of this manifestation of decay seems to show that these beds have been subjected to weather for a much longer period than the gravels of the region to the northward.

The other group of split pebbles, of which the fracturing was done before the fragments came to their present position, is more puzzling. Pebbles of this class present distinct fracture faces, which are usually in joint planes. These fracture faces are a little rounded, the rounding being about what is found in unpolished paleolithic implements, or that measure of rounding which comes from a small amount of friction. In no case are the fragments which are separated from the slightly rounded pebbles found in connection with them. In some cases the edges of the stones are slightly chipped, making them appear like the secondary fractures which the savage implement-maker formed on the stones (Pl. X).

At first sight a large number of these faceted pebbles look like imperfect stone implements; to my eye they closely resemble the interesting implement-like stones from the gravels near Trenton, N. J. It is often, indeed, difficult to resist the conviction that some selected specimens are the result of human labor. A careful inquiry, however, has led me to the conviction that they are all natural products. This inquiry was conducted in the following manner, viz, gathering an extensive collection of these stones it was observed that they were far too common in the drift to make it reasonable to suppose that they had been the work of man. It was also evident that the range in size of these fragments was far too great to justify the supposition that they were of artificial origin. Specimens weighing 20 or 30 pounds were not infrequently observed; these were evidently too large to have been used as implements; others were found not exceeding an inch in length, which were clearly too small to have served any useful purpose.

Moreover, out of a hundred specimens, on the average not over one or two were chipped in a way which it would be reasonable to suppose a savage would have chosen to adopt in order to bring the stones into a shape suitable for any of his limited needs. The gradation between the specimens, which are so like unquestionable stone implements that they would readily be accepted by the collector as the work of the human hand and those which would be unhesitatingly rejected, is singularly complete and well calculated to persuade the unprejudiced observer that all the artificial-looking fragments from the kames and terraces of Nantucket are of natural origin. It is clear that the occurrence of such chipped and polished fragments resembling works of art shows us how careful we should be in classing as man's work fragments of stone which have been selected from a great many chipped pebbles.[1]

These chipped and somewhat polished stones may be accounted for in a natural way, thus: Let us suppose that the pebbles were formed and transported to near their present position by the glaciers during the first part of the ice age and left in the form of kame and till deposits for a long period during which they were exposed to the influences of decay. In this period of repose their incipient joints were developed, as the joints are now developed everywhere in the pebbles buried in the kame deposits. Next, in a readvance of the ice, these pebbles were forced forward and thereby submitted to strains which separated the fractured portions from the mass of the more or less chipped fragments; the transportation led to the rounding of the exposed edges and to the partial polishing of the fractured surfaces. We would then have the pebbles in the shape in which we now find them; and the enthusiastic collector, selecting one in a hundred of these fragments, would suppose that he had discovered implements which were accumulating on the ground during the glacial period.

The full bearing of these observations on the discoveries made by Dr. C. C. Abbott in the region about Trenton, N. J., can not be discussed in this memoir. It still seems likely that the collections of chipped pebbles gathered from the Delaware drift contain a large number of fragments which have been worked by human hands. However, on comparing the large and fairly representative collection of these pebbles contained in the Peabody Museum, at Cambridge, Mass., with specimens which abound at Nantucket, I am convinced that the whole problem requires a very careful discussion from the point of view of the geologist, as well as from that of the ethnologist.

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[1] It seems to me that we may for the criticism of such materials make a simple rule, based on experience, which is as follows: Where the stones appearing to be artificially worked are mingled with many similarly chipped stones which can not be regarded as artificial, we probably have a case similar to that above cited. Where the supposed implements are not so mingled with similar pebbles evidently of natural origin we shall run little risk in classing them as artificial objects.

These artificial-looking stones are found in relatively great abundance in all the pebble-drift sections exposed at Nantucket. At Sankaty Head they occur at a depth of 25 feet or so at the crest of the cliff, in positions which seem to indicate that they could not have slipped down from the surface. It is hardly possible to explain the occurrence of these fragments on the supposition that they are artificial in any way that is consistent with the demonstrated facts concerning the history of the Glacial Period. The pebbles themselves must have been formed during the glacial period, for the whole of this upper or kame drift rests upon a layer of till produced during the first great advance of the ice, and they are overlaid by what appears to be till of a later age. Apparently all the work of man on these materials, if indeed any such work has been done, must therefore have been accomplished in the interval between the retreat of the glacier after the first part of the ice epoch and the second advance of the glacier. We have to suppose that in this relatively brief interval savage men strewed the surface with chipped stones in a measure unknown in any part of the earth's surface, however long occupied by primitive people; otherwise, when the surface was swept by the readvancing ice sheet and the superficial material commingled with that which was below, forming the vast kame heaps which the glacier pushed forward to its front, these chipped stones would not have abounded in it as they do on this island, at Trenton, and probably at other points on the ice front.

Let us imagine the glacier to return to the present surface of New England, sweeping away all the superficial materials now resting upon it, and accumulating along a new ice front the débris which was not ground up in transportation. What would be the chance of finding in this deposit any remains of the Indians who lived during the Glacial Period? Manifestly their remains would be almost inconceivably rare. The explorer would be probably well rewarded with a single find in a lifetime of search, so slight would be the chance of a fragment of art work surviving the accidents of a glacial journey.

The worked stones and the other substantial elements of our modern arts in New England would afford thousands of times as many fragments as all the stone hatchets and similar tools which the aborigines left on the surface of this country, and yet I doubt if the remains of our arts would be as plenty in the frontal moraine of a new glacial period which should overtake us as these implement-like fragments which are now found at Nantucket.

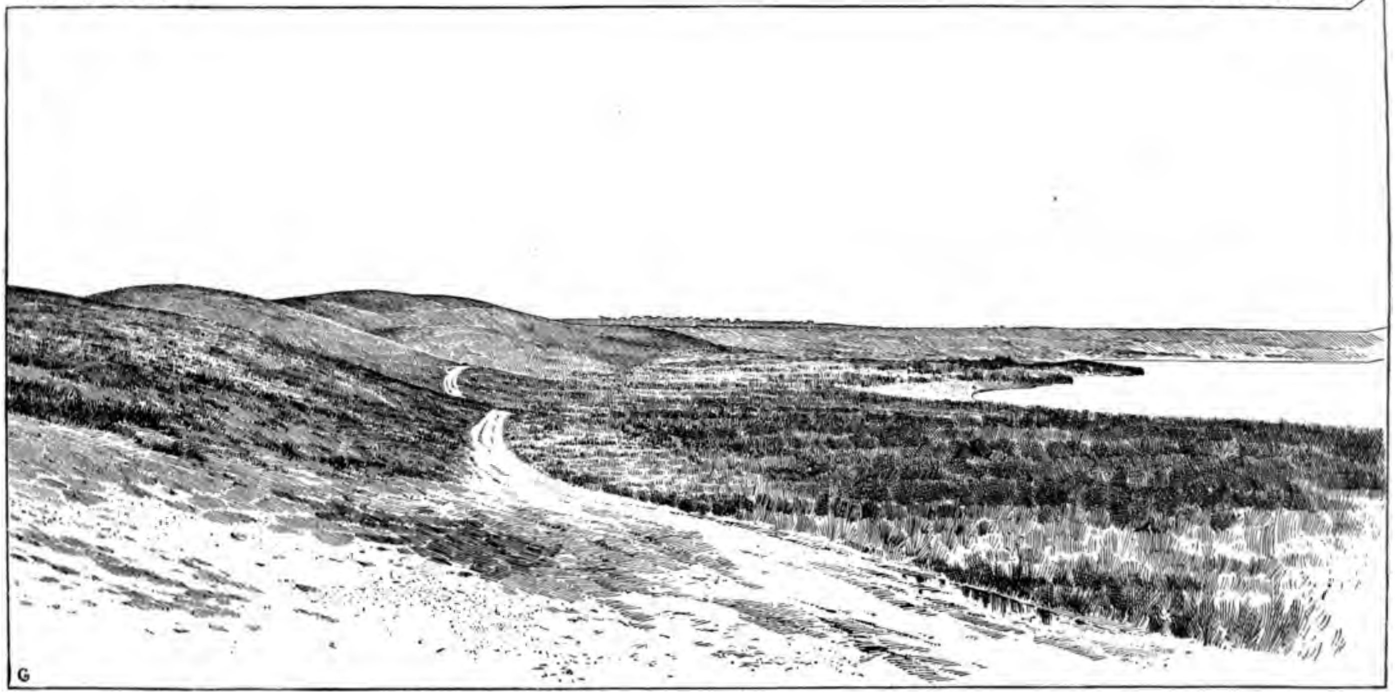
One of the considerable difficulties which we encounter in assigning an artificial origin to these frontal drift fragments arises from the fact that none of them appear to be worn on their cutting edges. It may be said that they were used for striking blows and not for cutting bones, sinews, and other hard substances. If this were the case we should find other forms of implements which were so used, for we can not believe that there was ever a tribe of savages making stone implements for the single purpose of striking blows, who neglected the equally serviceable uses in which the edges of the stone would have been worn.

ORIGIN OF THE DETRITAL MATERIALS.

The mineralogical features of the pebbles of the drift in this region have especial interest, inasmuch as they afford some information concerning the nature of the rocks which lie to the northward of Nantucket but which are deeply covered by the mantle of detrital material. About all we may ever know concerning these deposits we shall learn from a study of the drift materials derived from them. On this account I have paid especial attention to the pebbly deposits of the island. The exposures of the underlying till are so scanty and the pebbles contained in the exposed portion so few and small that no effort has been made to ascertain the variety of rocks represented in this portion of the ice-borne material. The only examination has been of the stratified gravels.

It should be noted that the distance to which the fragments contained in the bowlder clay have been carried is much less considerable than that to which the stratified or kame gravels have been conveyed. In the valley of the Taunton River, which is the nearest considerable basin on the mainland, the average distance to which the kame fragments have been carried is at least three times as far as that to which the till materials have traveled. The result is, that the kame or stratified gravels give us information of a less accurate because less localized nature than we may obtain from the study of the fragments from the till.

The pebbles of the stratified gravels on Nantucket are in large part derived from the group of granitic rocks known on the neighboring mainland; probably nearly one-half of the whole mass is of this nature. Of the remainder a considerable part is composed of felsites and felsite porphyries such as are common in the region of Boston, Mass. On the eastern end of the island these porphyrite and felsite materials are much more abundant than on the western portion. In the region about Sankaty Head these porphyritic pebbles are plentifully intermingled with somewhat angular fragments of volcanic breccias of a type unknown to me in any part of southern New England, though they much resemble the ash beds and breccias of the eastern portion of the shore of Maine, especially those found near Eastport. Although the felsites



JUNCTION OF KAME MORAINE AND TERRACE PLAIN ON GIBBS POND; SIASCONSET IN THE DISTANCE.

near Boston are only 60 miles away, I am disposed to believe that these fragments of porphyry found on Nantucket are derived from localities which are much nearer this island. The very angular nature of some of the fragments leads me to believe that they are from a field not more than 30 miles to the northward of the place where they are now found. There is a variety of stratified rocks, clay, slates, and sandstones and conglomerates in this drift material. The conglomerates and sandstones have the aspect of the deposits found in the Narragansett Coal Measures, especially those near Taunton, Mass. No distinct plant fossils or other organic remains have been found in these fragments, but several of the best of them show traces of carbonaceous matter, and in one instance a large bowlder lying near the village of Siasconset was found to contain faint traces of fossil plants.

Some of the bowlders of conglomerate have their pebbles much compressed, as is often the case in the mill-stone grit bed of the Narragansett coal fields, but only rarely so in the conglomerates near Boston. Mingled with these coal-measure pebbles is an abundance of large bowlders of white quartz, such as plentifully occur in veins in the much altered coal measures about Narragansett Bay, but which are rare in other parts of southern New England. Knowing that these materials are from a coal basin, the question arises whether they are derived from any part of the Narragansett field. Assuming as before that the direction of carriage of this drift was from the northwest, we find that the only part of the Narragansett basin lying in the path traversed by the glacial stream which brought the pebbles to Nantucket is in the narrow strip of those rocks extending northeasterly from Taunton through Bridgewater up to and a little beyond the village known as Queen Anne's Corner, a district which lies about 50 miles from Nantucket. The considerable size and the nature of many of these fragments are much against the supposition that they have journeyed so far. I am inclined to believe that they are from some area of carbonaceous rocks not farther away than the southern shores of Cape Cod.

If we assume that the direction of the ice movement at the time when the Nantucket moraine was formed was at right angles to the frontal line of that moraine, then these materials derived from the volcanic and the Carboniferous rocks probably could not have come from any part of the Narragansett field; they must have been derived from deposits of that age which lie either below the surface of Cape Cod or under the ocean to the north or south of it. The extreme western limit whence they could have journeyed must have been a meridional line lying at least ten miles to the east of Boston. In general it is a tolerably fair assumption that an extended moraine front was formed by an ice stream which moved down at right angles to the line of the accumulations. I am therefore disposed to believe that all the glacial waste of Nantucket, except perhaps the bowlders transported by icebergs, came from far east of the Narragansett basin.

Besides the above-mentioned stratified rocks there is a considerable amount of clay slate in the pebbles of Nantucket. These slates are represented by small though numerous fragments. A careful search failed to show any distinct fossils in them; in their physical condition they are more like the Carboniferous deposits of this section than any other deposits of this nature known to me in southern New England.

At no point on Nantucket have I found any distinct evidence of detrital matter such as might have been derived from Tertiary deposits like those which occur on Martha's Vineyard. This should not be taken as evidence that the Tertiary strata do not exist beneath this section. It may be that the beds of that age are deeply covered by the blue till, and that the last invasion of the ice was thus fended from them.

FOSSILIFEROUS DEPOSITS.

The fossil-bearing deposits of Nantucket are confined to two small groups of strata; one of these consists of fresh water peats, the other of areas of stratified sands containing a variety of marine species.

The fresh water marsh deposits are found, here and there, over the whole surface of the island. They consist of ordinary peats, and at first sight appear to have no special geological interest. On the shores of the island, however, there are, at several points, deposits of these peats which at present lie several feet below the level of high tide. These submerged fresh water peats appear to be particularly abundant in the sections from Tom Never's Head to Squam Head. Every heavy storm throws up considerable quantities of this peaty matter. The largest fragments are found on the beach a little south of Siasconset, but they may be observed at any time of storm along the whole of this eastern shore. The material, though not in any way changed from its original character, is interesting for the reason that it lies below the level of low tide, and also from the fact that it contains many beetles and other insects. There is another locality where the peats appear below the high tide level; this is on the north shore, about one mile west of the harbor of Nantucket, not far from the pumping station which supplies the town with water. At this point the peat is disclosed at low tide, and is there seen to cover an area of several thousand square feet. (See Fig. 9.)

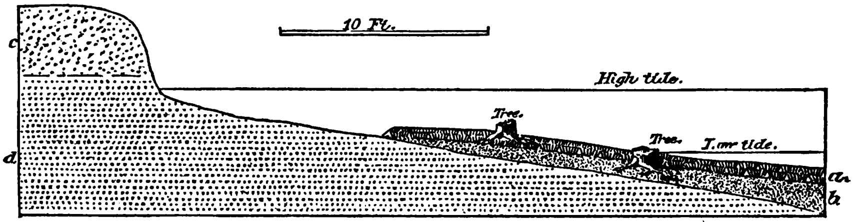


FIG. 9. Section of submerged swamp, north shore.
a, swamp; *b*, ferruginous sand; *c*, dune sand; *d*, stratified drift.

These submerged peat deposits contain abundant remains of insects. These are most plentiful in the deposits which occur along the eastern face of the island.

At first sight it appears as if these submarine peats might have been formed at their present levels in pools which were originally at a distance from the sea, but to which the sea has attained by the recession of the shores. There can be no question that this is the way in which the sea has come to invade these peaty deposits, but it seems doubtful whether we can explain their present elevation without supposing that the deposits have been somewhat depressed since the time of their formation. Ordinary spongy peat is now forming in many existing pools of the island below the level of high tide for the reason that the bottoms of the pools of fresh water are a little below that level; but the crowns of living trees never lie below the high tide mark, and even the rushes which grow on the margins of the swamps rarely, if ever, have their roots as low as the tide line. In these peat deposits on the north and northeast shores not only are the crowns of the rushes below the high tide line, but at one point we find the crowns and roots of a tree ten inches in diameter standing in the natural attitude about two feet below the highest tides and in a position where it is covered by the sea water. The roots of this tree were sufficiently exposed to view to make it clear that it was in the position where it had grown. It is not possible from fragments to determine its species in a clear way, but it is probably a variety of oak.

It is not admissible for us to assume, as we may in some other cases where trees grow below high tide mark, that this marsh deposit has been depressed by the local erosion of the base on which it stands. The area of swamp in which it occurs has the basin shape proper to the bottom of the basin-shaped pools found elsewhere on the island. A section excavated through the swamp shows that it rests upon the clay underlying all such accumulations, and that below the clay there are deposits of ferruginous sand. It would have been impossible for the waves to cut under this section in such a manner as to lower it gently beneath the sea. It is equally impossible to believe that the crown of any of our northern species of trees would have grown below the level of the water. I am therefore compelled to assume that this area has subsided since the above mentioned tree grew. The amount of the subsidence can not be less than two feet, that being the height to which the tides sometimes rise above the present level of its crowns. The roots of this specimen or those of a similar tree are found at least another foot further below the level of tide line. Moreover, as the existing swamps of the island which have or very recently had trees about their shores lie two or three feet above the sea level, it seems safe to assume that the tree when it grew had its crown at least five or six feet above its present altitude.

So far as I am informed this is perhaps the clearest evidence which has been obtained showing recent subsidence along this part of the New England coast. As to the date of the subsidence no evidence seems obtainable from this locality. The peaty matter has a very fresh and unconsolidated aspect. The roots of the rushes which it contains are singularly recent-looking; they are little decayed, and indeed seem to retain some part of their color and odor.

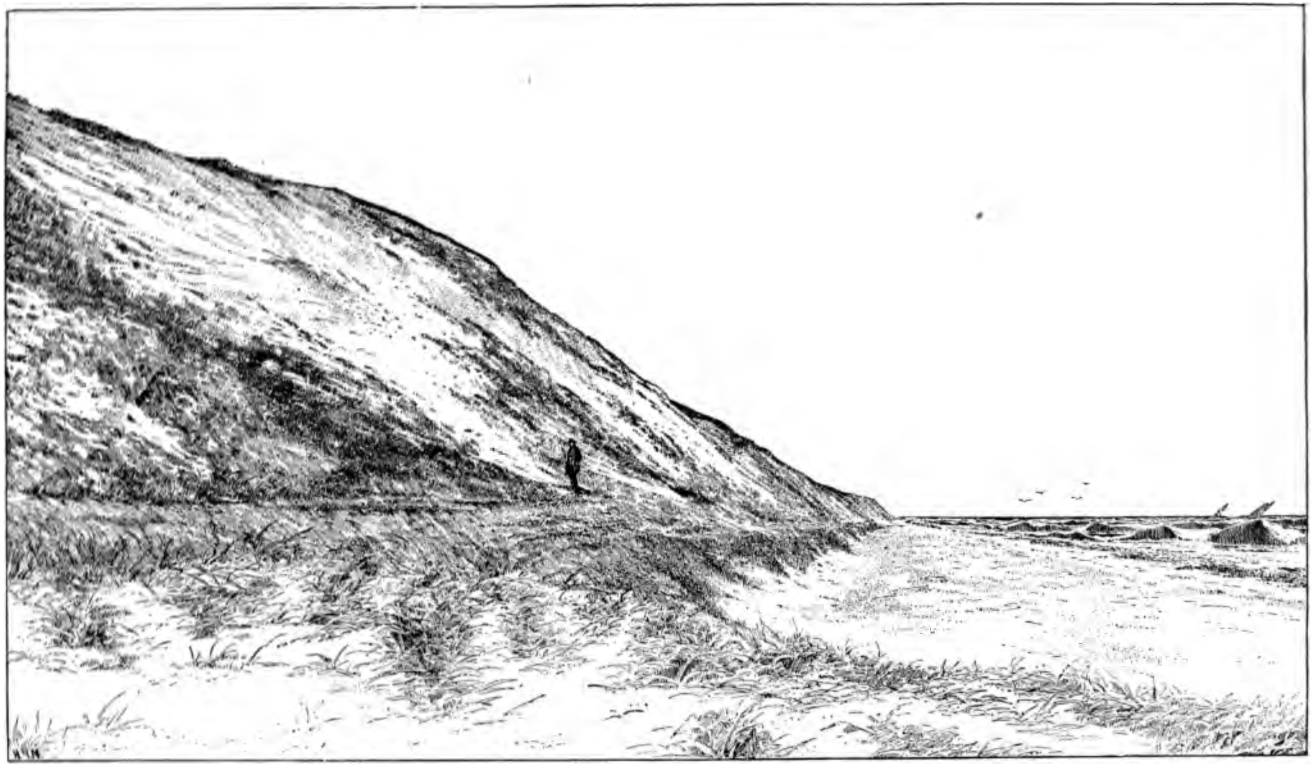
No other of the depressed fresh-water peats of this island exhibit their beds in place even at the lowest tides. They appear elsewhere than on the north shore to be covered by the deposits of sand, or are perhaps too deeply submerged to be exposed at the lowest stages of the tides. Still they contain fragments of roots of trees of considerable size, which may belong to some of the many species of shrubby plants which are tolerant of fresh water.

The evidence of marine deposits above the present level of the sea is, as has been long known, abundant on Nantucket. These deposits, so far as exhibited by natural sections, are limited to the east side of the island. This apparent limitation is probably due to the absence of natural sections elsewhere than on that part of the shore, for it is only on this eastern face of the island that we have any very extensive sections which clearly expose the stratified sands to a considerable depth. I am informed that at various points in and about Nantucket village deposits of shells have been encountered in digging the shallow wells, which never descend below high-tide mark. I have been unable to obtain any specimens of these fossils; but, as their presence is attested by Prof. Henry Mitchell, there can be no doubt that sands and gravels of the last stage of the Glacial Period containing scattered patches of fossiliferous beds, probably of the same age as those exposed at Sankaty Head, exist in other parts of the island.

FOSSILIFEROUS DEPOSITS OF SANKATY HEAD.

These fossiliferous beds of Sankaty Head appear in a cliff which has a height of about eighty feet above the high-tide mark. This cliff is cut through a portion of the kame gravels, which form a sort of elevated rolling terrace near the southern border of the true frontal moraine. The top of this terrace has a broadly rolling surface, and may be regarded as forming the zone of passage from the frontal moraine to the plain which lies on the southern part of the island. (See Pl. VII.)

The section at Sankaty Head is at present almost entirely hidden by the thick growth of grass and other plants, which have found a hold upon the surface since the sea has been fended from it by the considerable northward extension of the Siasconset apron-like beach. This is to be regretted, for the reason that it is from a geological point of view by far the most interesting section of the island and one of the most important found on the New England coast. It has been the ob-



SANKATY HEAD, LOOKING NORTH FROM A POINT 150 YARDS SOUTH OF LIGHTHOUSE.

ject of considerable study by several distinguished naturalists. In 1849 Messrs. E. Desor and Edward C. Cabot published in the proceedings of the Geological Society of London a short paper giving an account of this locality. At that time and for many years afterwards the continued inroads of the sea preserved a fresh face on the escarpment.[1]

The section as given by Messrs. Desor and Cabot is shown in Fig. 10. It differs from any I have been able to obtain in the present condition of the escarpment in certain important parts. It will be observed that at the base of the section the above-named authors indicate a bed of brown clay of unknown thickness which rises for 20 feet above the sea level. Above that point to the height of 33 feet they place successive layers of sand, gravel, and clay containing fossils, still higher in the section for a distance of 52 feet successive layers of sand and gravel without fossils, then a thin layer of peat one foot in thickness capped by six feet of dune sands, the whole forming an escarpment which rises 92 feet above the beach. The total height of the cliff as given by them is at least 15 feet greater than its actual altitude. It will be noticed also that the lower stratum of brown clay, which according to this section extends to a height of 20 feet above the sea level, is shown to be unconformably related to the gravelly layers which appear above it. It was the opinion of these observers that this lower clay belonged to the series of deposits which appear at Gay Head, and on this hypothesis they construct a highly ideal section, shown in Fig. 2 of their report, in which the Gay Head clays appear in the form of a syncline, the trough of which includes all the area between Sankaty Head and the western extremity of Martha's Vineyard. There is at present no trace of this brown clay at any part of this escarpment, nor was the thin layer one foot in thickness of tough clay, occurring according to their section at the height of 26 feet above the water line, found in my examinations. (See Fig. 10.)

The exhibition of this lower clay at the time Messrs. Desor and Cabot made their examination must have been clear, and the unconformity which they note was probably evident, as will be seen from the following extract from their report:

> The strata thus enumerated seem at first horizontal, but in digging along their edges we soon ascertained that they all dipped to the west, their inclination varying from fifteen to five degrees, the upper beds being generally less inclined than the lower ones. The inferior clay stratum, however, was found to differ considerably from the others, its dip being nearly thirty degrees to the southwest, and in some places even as much as forty degrees.
>
> These circumstances induced us to examine this lower clay stratum more carefully. Having made out a spot where the overlying gravel bed was seen in immediate contact with the top of the clay, we could distinctly trace its unconformable deposi-

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[1] On the Tertiary and more recent deposits in the Island of Nantucket, Messrs. E. Desor and Edward C. Cabot, in a letter to Sir Charles Lyell, president of the Geological Society: Quart. Jour. Geol. Soc. London, vol. 5, 1849 (proceedings), p. 340.

tion, the gravel being seen dying out towards the more inclined clay stratum, as shown in the above section taken on the side of a gully in the cliffs. * * * A considerable change of level must have taken place between the deposition of the clay and that of the gravel.

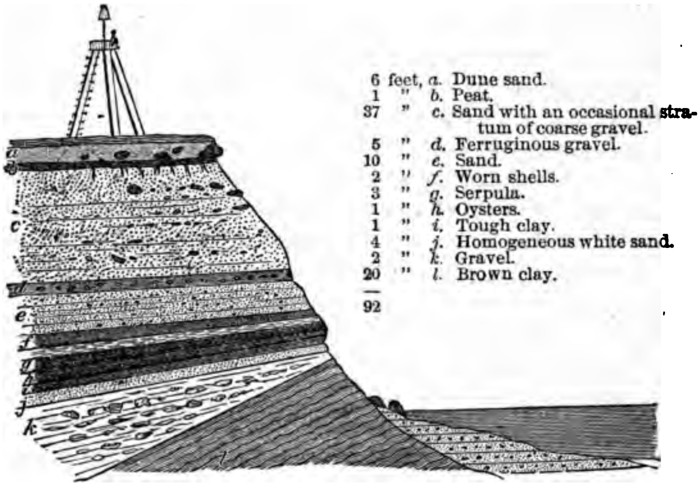

Fig. 10. Section at Sankaty Head.

This statement compels us to believe that the lower clay was exposed to view at the time when Messrs. Desor and Cabot made their examination. This was probably in the year 1847. It will be noticed, as is indicated in the section, that a slight recession of the cliff in the direction in which it was then rapidly wearing would carry the shore-line across the exposure of the brown clay, and that a wearing back of 20 feet would in good part, if not entirely, destroy the exposure. It is not improbable that this recession has taken place and that this bed has disappeared from view.

This hypothesis is borne out by the results of a study of this section made in 1874 by Mr. S. H. Scudder, which is contained in a memoir by Prof. A. E. Verrill, On the post-Pliocene fossils of Sankaty Head, Nantucket Island.[1] At the time when Mr. Scudder made his observations the clay described by Messrs. Desor and Cabot was still visible. As his observations differ in an important way from those made by the above-named gentlemen, I give his note in full:

> The sands and gravels forming the bluff at Sankaty Head, Nantucket, rest at base upon a thick bed of light-brown sandy clay of uncertain thickness, but extending upward to about 20 feet above the sea level. As the beds which rest upon it dip to the southwest, and as the anchor brings up clay from Sankaty Head eastward for half a mile, this clay bed is probably of great thickness.
>
> The brown clay is overlaid by 4 feet of gravel and coarse sand, the coarser parts mostly confined to three or four inches of the uppermost levels; the upper bed is more or less ferruginous, and hardens on exposure into a rather compact conglomerate.

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[1] Am. Jour. Sci., 3d series, vol. 10, 1875, pp. 364-375.

To this stratum must doubtless be referred a single specimen of a bivalve (probably a mactra), with valves half open, picked up on the bluff, embedded in a gravel conglomerate, and like it strongly impregnated with iron. The gravel is followed by about four feet of sands, subdivisible into separate beds, viz: At base, an inch or two of a very fine loose white sand, followed by nearly two feet and a half of a little less fine, closely packed, white sand, with irregular ferruginous streaks through its mass; this is covered by 9 inches of a coarse beach sand, with a still coarser sand in pocket; and this again by 9 inches of a very fine white sand. Above this comes a foot of ferruginous sand closely packed with masses of tough blue clay, much exceeding the sand in bulk, and forming the floor of the fossiliferous beds.

These consist first, at base, of 22 inches of coarse sand, in which the oyster, quahog, and common clam are the prevailing forms, the first predominating to such a degree as to make the name of oyster-bed the most appropriate. This merges into a serpula-bed, about 28 inches in thickness, made up almost altogether of large masses of serpula packed in sand and almost wholly devoid of other fossils. The bed of worn shells superimposed on this is about 22 inches in thickness and closely resembles *coquina*, except in the entire want of adhesion between the fragments.

This bed is followed by about 10 feet of fine, white, thinly bedded sand, and this by the stratified drift of the island, to a depth, as estimated by Desor and Cabot, of 42 feet. The foot of peat mentioned by them is wanting at this exact locality (though present a few hundred feet farther south), leaving the drift covered by five or six feet of dune-sand, more or less intermixed with loam below.

On following the bed of broken shells along the face of the cliff it was found to thin out to about a foot in thickness 25 feet on either side of the most prominent point, where the section was made, and which has doubtless been longer protected than the other parts of the bluff by the former presence of a great mass of clay next the water's edge, called "Antony's Nose;" beyond these 25 feet the bed of broken shells becomes more or less obscured by an admixture of sand, gravel, and serpula, and is entirely lost at 40 feet distance on either side.

The strata, from the lowermost clay to the bed of worn shells, all dip to the southwest. The uppermost beds incline along the face of the cliff three degrees to the south, while the inclination to the west (along the section dug out of the cliff) is eleven degrees, making a dip of nine degrees to the southwest. All the beds below this also incline eleven degrees to the west, but the inclination of their face toward the south increased gradually in passing downward until that of the upper edge of the lower clay reaches eleven degrees, making a southwesterly dip of this bed seventeen degrees to the southwest. There is no evidence of any thinning out of the gravel-bed, as stated by Desor and Cabot, nor of any unconformability between this bed and the underlying clays; but, on the contrary, every appearance that the latter belong to the same continuous series as the former.

It is worthy of note that the fossils of this locality lie above the clays instead of in the clays, as in most of the New England localities of post-Pliocene marine shells.

It will be clearly observed that Mr. Scudder seems to have seen the clay, or rather sandy clay, found by Messrs. Desor and Cabot, but he failed to find any evidence of unconformability between this clay and the overlying fossiliferous sands. It is likely, however, that the aspect of the section had changed a good deal in the score of years which had intervened between these two observations. I think it probable that the observations made by the earlier geologists were good in the conditions of the cliff at the time when they were made.

I am disposed to believe that this lower sandy clay is not related to the deposits at Gay Head, but that it represents the upper portion of the lower till at Nantucket, which, as is shown in some parts of Squam Head, in the neighborhood of Polpis Harbor, on the north shore, and in the village of Nantucket, often contains very few pebbles, and presents in general the appearance indicated by the terms applied to it by the above-named observers. It is possible, however, that although not synchronous with the Gay Head deposits, it may be of the same age as the clays which occur on the southern shore of Chilmark.[1]

The most interesting portion of Professor Verrill's important memoir concerns the distribution of the fossil contents of this section. He divides this section into an upper and lower series of strata, between which there are considerable differences as to the character of their fossil contents. The exact line which separates these two portions of the section is not indicated save in the description given by Mr. Scudder. Inasmuch as this list of fossils is of great value to those who may be engaged in the study of quaternary fossils we give it in full.

List of species from the lower shell-bed.

MOLLUSCA.

Tritia trivittata Adams. Common.

Florida to Gulf of St. Lawrence; low water to 40 fathoms. Fossil in the post-Pliocene of Point Shirley, Gardiner I., Virginia, and southward; in the Miocene of Maryland, South Carolina, etc.

Ilyanassa obsoleta Stimpson. Common.

Florida and Gulf of Mexico to southern Maine; local in the southern part of the Gulf of St. Lawrence; littoral to 2 fathoms. Fossil in the post-Pliocene of Point Shirley, Virginia, South Carolina, etc.

Urosalpinx cinerea Stimpson. Common.

Tampa Bay and eastern Florida to Massachusetts Bay and local farther north to Gulf of St. Lawrence; littoral to 10 fathoms. Post-Pliocene fossil at Point Shirley, Gardiner I., Virginia, and southward; in the Miocene of Maryland.

Eupleura caudata Adams. One fine specimen.

Gulf of Mexico and eastern Florida to Cape Cod; low water to 8 fathoms. In the post-Pliocene from Virginia to Florida; Miocene of Maryland and South Carolina.

Astyris lunata Dall. One specimen.

Alabama and Florida to Massachusetts Bay; low water to 14 fathoms. Fossil in the post-Pliocene of Gardiner I. and South Carolina.

Cerithiopsis Greeni Verrill. Four specimens.

South Carolina to Massachusetts Bay; 2 to 10 fathoms.

Crepidula fornicata Lamarck. Abundant.

Gulf of Mexico to southern Maine, and local in the southern part of the Gulf of St. Lawrence; low water to 15 fathoms. Post-Pliocene fossil at Gardiner I., South Carolina, etc.; and Miocene in Maryland and South Carolina.

Crepidula plana Say. Common.

Distribution same as the preceding, from which, however, it is very distinct.

Crepidula convexa Say. Not common.

Distribution like the two preceding, from both of which it is perfectly distinct (although confounded with *C. fornicata* by Tryon and others). Fossil in the post-Pliocene of Virginia and South Carolina.

Odostomia trifida Gould. Common.

New Jersey to Massachusetts Bay: low water to 5 fathoms.

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[1] *Geology of* Martha's Vineyard: Seventh Ann. Rept. U. S. Geol. Survey.

Odostomia impressa Stimpson. Common.

South Carolina to Vineyard Sound: low water to 5 fathoms.

Turbonilla interrupta Adams. Several specimens.

South Carolina to Cape Cod; local farther north to the southern part of the Gulf of St. Lawrence, near Prince Edward Island; low water to 15 fathoms. Post-Pliocene fossil at Gardiner I. and in South Carolina.

Saxticava arctica Deshayes. Rare and small.

Arctic Ocean to Georgia; local and rare south of Long Island; low water to 50 fathoms. Fossil in the post-Pliocene of Maine and everywhere northward.

Mya arenaria Linné. Abundant.

Arctic Ocean (lat. 78° N.) to South Carolina; low water to 40 fathoms. Post-Pliocene fossil from South Carolina and Virginia to Greenland and northern Europe.

Corbula contracta Say. One valve.

Florida to Cape Cod.

Ensatella Americana Verrill. Common.

Labrador to Florida; low water to 25 fathoms. Fossil in the post-Pliocene of Portland, Me., Point Shirley, Gardiner I., Virginia, and South Carolina; Miocene of Maryland, etc.

Angulus tener Adams. Several specimens.

Florida to Gulf of St. Lawrence; low water to 12 fathoms.

Cumingia tellinoides Conrad. Common.

Florida to Cape Cod; 3 to 12 fathoms. In the post-Pliocene and Miocene of South Carolina, etc.

Petricola pholadiformis Lamarck. Rare.

Gulf of Mexico to Massachusetts Bay; local in Casco Bay and southern part of the Gulf of St. Lawrence; low water to 4 fathoms. In the post-Pliocene and Pliocene from Florida to Virginia.

Venus mercenaria Linné. The variety abundant; a nearly typical form not uncommon.

Florida to Massachusetts Bay; local on the southwestern coast of Maine and southern shores of the Gulf of St. Lawrence and Bay of Chaleur; low water to 8 fathoms. In the post-Pliocene of Point Shirley, Gardiner I., Virginia, Florida; Miocene from Maryland to South Carolina.

V. mercenaria, var. antiqua Verrill. By this name I propose to designate the unusually massive and strongly sculptured variety to which most of the fossil shells belong, and which has been discussed on a previous page.

The shell is rather obtusely rounded posteriorly, and is thickly covered with prominent concentric lamelliform ridges, which mostly extend entirely across the shell, but are often reflexed, appressed, and more or less confluent over the middle region, where the ordinary variety is nearly smooth (except when young). The violet color can still be traced in some specimens entirely around the inner margin, as in many recent Nantucket examples.

Tottenia gemma Perkins. Few specimens obtained.

South Carolina to Labrador; low water to 4 fathoms.

Gouldia mactracea Gould. One specimen.

Florida to Cape Cod; 3 to 15 fathoms.

Scapharca transversa Adams. Very abundant and large.

Florida to Cape Cod; low water to 15 fathoms. In the post-Pliocene of Cape Cod, Gardiner I., Virginia, South Carolina; Miocene of Virginia and North Carolina.

Mytilus edulis Linné. Common.

Circumpolar; Arctic Ocean to North Carolina; littoral to 50 fathoms. In the post-Pliocene from Florida to Greenland and northern Europe.

Modiola hamatus Verrill. Common.

Gulf of Mexico to Long Island Sound and Narragansett Bay; littoral.

Crenella glandula Adams. Few specimens obtained.

Labrador to Long Island; 5 to 60 fathoms. In the post-Pliocene of Montreal.

Anomia glabra Verrill.

Florida to Cape Cod; and locally farther north to Nova Scotia; littoral to 20 fathoms. In the post-Pliocene and Pliocene of South Carolina.

Ostrea Virginiana Lister. Abundant and well-grown.

Gulf of Mexico to Cape Cod, and locally farther north, at Damariscotta, Me., and in the southern part of the Gulf of St. Lawrence; low water to 5 fathoms. In the post-Pliocene of Point Shirley, Gardiner I., South Carolina, etc. Both the short, rounded specimens and the much-elongated and narrow forms occur, as well as all the intermediate states, just as in many modern oyster-beds, showing that in post-Pliocene times the same kind of individual variations prevailed that have perplexed many modern systematists, but they have not yet become specific, nor even definite varietal characters.

BRYOZOA.

Hippothoa variabilis V. (*Escharella variabilis* Verrill, in Report on Invert.) Common on *Serpula*, etc.

Florida to Massachusetts Bay; low water to 20 fathoms.

Biflustra tenuis V. (*Membranipora tenuis* (Desor); Verrill, in Report on Invert.) Common on shells.

Delaware to Massachusetts Bay; low water to 15 fathoms.

Membranipora catenularia Smitt. Common on shells.

Arctic Ocean to Long Island Sound; low water to 50 fathoms. Northern Europe.

CRUSTACEA; ANNELIDA; PORIFERA.

Panopeus sp. Several claws were found.

Eupagurus pollicaris Stimpson. A claw, probably from this bed, is recorded by Desor.

Florida to Massachusetts; 2 to 15 fathoms.

Balanus eburneus Gould. Common.

West Indies to Massachusetts Bay; littoral to 3 fathoms.

Balanus crenatus Bruguiére. Common.

West Indies to the Arctic Ocean; 3 to 15 fathoms.

Serpula dianthus Verrill. Very abundant.

North Carolina to Cape Cod; low water to 15 fathoms.

Cliona sulphurea Verrill. The excavations are abundant in oyster-shells.

Florida to Massachusetts Bay; 1 to 15 fathoms.

List of species found only in the upper shell-bed.[1]

MOLLUSCA.

Buccinum undatum Linné. Common.

Arctic Ocean to New Jersey; northern coasts of Europe; low water to 100 fathoms. In the post-Pliocene, Maine to Labrador and northern Europe.

Neptunea curta Verrill. Several specimens; one of large size.

Labrador to Massachusetts Bay, and in deep water farther south to Long Island.

Lunatia heros Adams. Common, but badly broken.

Georgia to Gulf of St. Lawrence; low water to 40 fathoms. Post-Pliocene, Canada, South Carolina; Pliocene, South Carolina; Miocene, Maryland to South Carolina.

L. heros, var. triseriata. One specimen occurred.

Neverita duplicata Stimpson. One broken specimen.

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[1] A valve of *Saxicava Norvegica* was found after this list was put in type. Arctic Ocean to Massachusetts Bay.—*Foot-note in Am. Jour. Sci.*

Yucatan to Massachusetts Bay: low water to 10 fathoms. Post-Pliocene, Virginia to Florida: Pliocene, South Carolina; Miocene, Maryland to South Carolina.

Crucibulum striatum Adams. One large specimen.

New Jersey to Bay of Fundy; low water to 40 fathoms.

Scalaria Grœnlandica Perry. Recorded by Desor, and doubtless from this bed.

Arctic Ocean to Block Island; 10 to 109 fathoms; northern Europe. Fossil in post-Pliocene of northern Europe.

Diodora Noachina Gray. Two good specimens.

Arctic Ocean to Cape Cod; 8 to 70 fathoms. Northern Europe.

Mya truncata Linné. Several large specimens.

Arctic Ocean to Nantucket Shoals; low water to 10 fathoms. Northern Europe. In the post-Pliocene, Maine to Labrador.

Thracia truncata Mighels and Adams. A few valves, special bed not indicated.

Greenland to Long Island; 10 to 60 fathoms.

Clidiophora trilineata Carpenter. One valve.

Florida to Gulf of St. Lawrence; low water to 30 fathoms.

Macoma fragilis Adams, var. fusca (Say). A few valves.

Greenland to Georgia; littoral to 6 fathoms. In post-Pliocene from South Carolina to Greenland.

Ceronia arctata Adams. Abundant and large.

Gulf of St. Lawrence to Long Island.

Mactra solidissima Chemnitz. Common, fragmentary.

Florida to Labrador; low water to 12 fathoms. Post-Pliocene of Point Shirley, Mass.

Cyclocardia borealis Conrad. Common.

Labrador to New Jersey; 3 to 80 fathoms. In the post-Pliocene of Gardiner I., Point Shirley, Labrador.

Cyclocardia Novangliæ Morse. A few valves.

Gulf of St. Lawrence to Long Island Sound; 3 to 40 fathoms.

Astarte undata Gould. One worn valve.

Long Island Sound to Northumberland Straits in Gulf of St. Lawrence; low water to 100 fathoms. In the post-Pliocene of Gardiner I. and Point Shirley.

Astarte castanea Say. Abundant.

New Jersey to Nova Scotia; 5 to 40 fathoms. In the post-Pliocene at Point Shirley.

Modiola modiolus Turton. Many worn valves.

Circumpolar; Greenland to New Jersey; low water to 80 fathoms. In the post-Pliocene of Point Shirley, Canada, and northern Europe.

Anomia aculeata Gmelin. Common.

Arctic Ocean to Long Island Sound; low water to 100 fathoms.

BRYOZOA.

Eschara verrucosa Esper. On shells of Ceronia.

Arctic Ocean to Nantucket Shoals; 3 to 45 fathoms. Northern Europe. In the fossil examples the surface of the cells is covered with radiating ridges, often rising into an eminence in the middle, and is perforated with numerous pores in the grooves. Orifice somewhat semicircular, with a median avicularium in front of the proximal edge.

Celleporaria incrassata Smitt ?. Several.

Off Martha's Vineyard to Spitzbergen; 10 to 160 fathoms. The specimens are thick, irregular masses. The apertures are small, rounded, oblong, constricted on the sides by small points projecting inward near the middle, and sometimes with a small proximal spine.

CRUSTACEA AND ECHINODERMATA.

Balanus portatus. Very abundant and large, but broken.

Arctic Ocean to Long Island Sound; 2 to 90 fathoms.

Strongylocentrotus Dröbachiensis A. Agassiz. Spines only.

Arctic Ocean to New Jersey; circumpolar; low water to 430 fathoms. Post-Pliocene of Maine and northward.

List of species found in both shell-beds.

Species.	Lower bed.	Upper bed.
Urosalpinx cinerea	Common	One.
Tritia Trivittata	Few	Common.
Ilyanassa obsoleta	do	Few.
Crepidula fornicata	Abundant	do.
Crepidula plana	Common	do.
Ensatella Americana	Abundant	do.
Mya arenaria	do	do.
Saxicava arctica	Few	Common.
Venus mercenaria	Abundant	Few.
Scapharca transversa	do	do.
Mytilus edulis	Few	Common.
Crenella glandula	do	Several, large.
Ostrea Virginiana	Abundant	Few.

Professor Verrill is of the opinion that—

> The fossils of the lower bed indicate, for the water, a summer temperature of 70° to 75° Fahr., while those of the upper bed correspond to a temperature of 55° to 60°, thus showing plainly the influence of the Arctic current along the coast. All the species still inhabit the waters of southern New England, except *Diodora Noachina,* found in the upper bed, but this occurs in Massachusetts Bay, and will probably be found hereafter in the deeper channels among the Nantucket Shoals.

All the species found in this section appeared to Professor Verrill identical with those now found along the shores of this region except the quahog (*Venus mercenaria*). In these shells he notes certain slight but apparently unimportant peculiarities. It does not seem possible to conclude from the difference in the character of the shells in the upper and lower parts of the section that any general climatal change in the temperature either of water or of air took place at the time when these two portions of the section were formed. The result may have been due altogether to changes in the direction of the ocean current, changes dependent on geographical modifications, which may have occurred at considerable distances from this point.

A diagrammatic section of the cliff, as far as it is determinable in the present condition, is given in Fig. 11. It will be seen that, as shown at present, the fossils occur at various levels in the bed, some of the species occurring as much as fifty feet above the surface of the water. The deposit is, throughout, composed of alternating layers of sand and pebbles. Save in the upper fifteen or twenty feet of the section, the pebbles are rather small, few exceeding three inches in diameter; near the top they are coarser and more angular, resembling the matter of a frontal moraine which has been stratified. In this uppermost section the fossils are wanting.

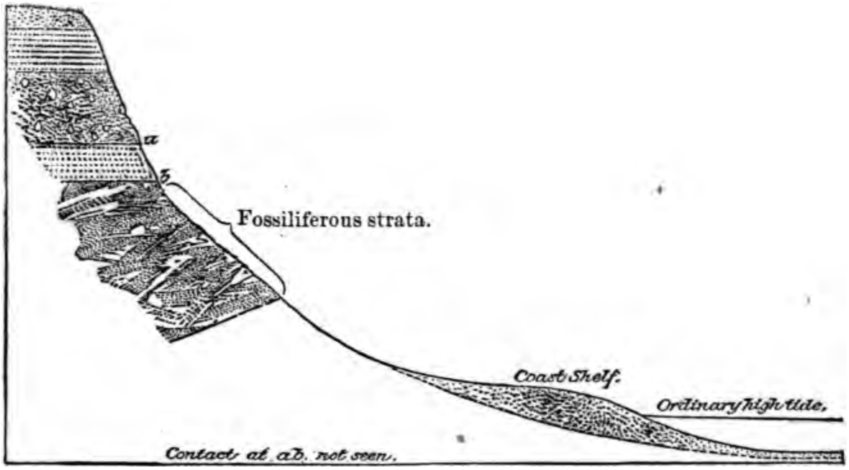


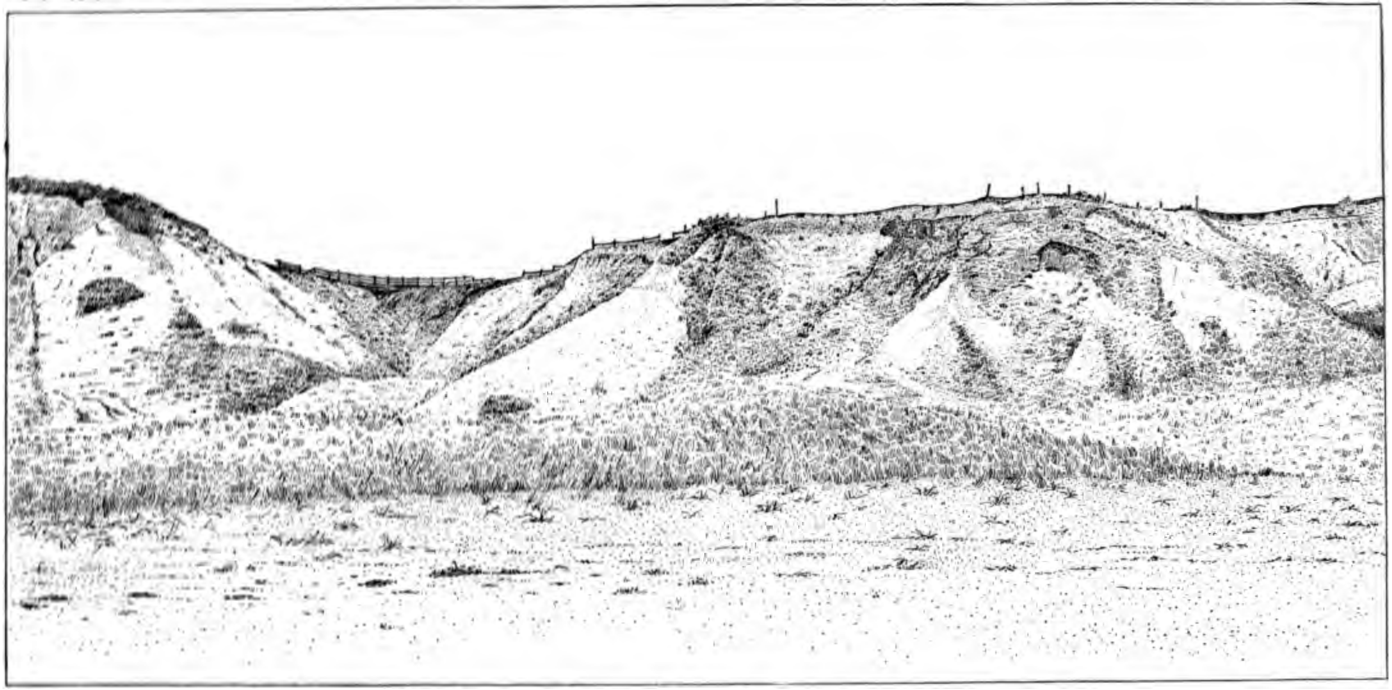
FIG. 11. Diagrammatic section of beds at Sankaty Head. *a*, peat beds; *b*, tops of glacial drift.

The distribution of the fossils in the part of the section where they are found is extremely curious; they occur as small isolated patches, lying generally at a considerable angle, dipping in most cases to the southwestward. The specimens are usually in a fragmentary condition and are packed together as if by the action of waves or by motion of swift currents. It is evident that a larger part of these remains were not formed just where they lie, but were swept into their position after having been comminuted by the waves. As will be seen from the list of fossils given above, the species are all those which belong to shallow water in the parts of the shore which are open to the wide sea. This leads me to the belief that the fossiliferous deposits now exhibited at Sankaty Head were formed along an old beach line. The considerable thickness of the section in which they occur, which is 50 feet or more in depth, makes it necessary to suppose that the shore line remained near this place for a considerable time.

The upper part of this section for ten to twenty feet is pretty sharply divided from the lower fossiliferous portion, not only by the absence of fossils in its strata but by the disposition of its materials. The bedding from the base to the height of about fifty feet is, wherever observable, of the irregular, stratified type characteristic of the shore. Above that point, where the fossils cease to appear, the bedding becomes more horizontal, in this resembling our ordinary terrace drift, such as is found on the main-land and is exhibited in the terraces on the southern part of the island. Here, as everywhere else, so far as observed, these regular stratified terrace deposits are devoid of organic remains. Above this last-named deposit lies a mass of apparently unstratified coarse pebbles, which, though wanting the clay element so generally found in the till, probably is of that nature. This is capped by a layer of blown sand of very recent origin.

At a point about five hundred yards south of Sankaty Head lighthouse there is a section exposed which differs in an interesting way from that on the higher and more northern section of the cliff. The escarpment has a height of about thirty feet. The general nature of the ore deposits, which are fairly well disclosed, is indicated in Fig. 12. It will be observed that besides the variation arising from the presence of peat deposits and layers of bog iron ore, which may be fairly considered unimportant, the section departs in essential regards from that figured in the section given by Messrs. Desor and Cabot and that which represents the present condition of the higher cliffs. The till-like deposit near the top of the main section has apparently become in a southward extension of a few hundred yards a stratified clayey sand with angular pebbles. The sands next lower in the sections are apparently alike in thickness and character. But the fossiliferous sand is entirely wanting, unless it be represented by some small fragments of shells found on the talus at the point indicated in Fig. 12. The lower greenish gray clay appears to be identical with the deposit which I have considered as till in other parts of the island, where its character is much more distinct than at this point. I am disposed to believe that this blue clay may be the equivalent of the deposit which Messrs. Desor and Cabot considered of Tertiary age. In color and character it closely resembles the clay which overlies undoubted till at other points on the island. The contact between this stratum of clay and the overlying sands has not been seen, but from the imperfect indications I am inclined to believe that it is probably irregular, i. e., that the surface of the clay was, to a certain extent, eroded by the action of water or of ice before the sands were laid down. (See Pl. VIII.)

This sudden change in the character of the section is possibly due to the fact that within the interval which separates it from that at Sankaty Head we pass from the southernmost limit which the ice sheet attained in its last advance to the region where the sea-floor received the deposits of sand and gravel which came from the subglacial streams. It is likely that during the second stage of the last Glacial Period, the ice for a time extended beyond the southern shores of Nantucket. This is indicated by the rounded character of the mass of till which lies between the two arms of Hummock Pond, as well as by the extensive deposits of apparently morainal matter which exist in the ridges of Nantucket Shoals. But in its retreat the glacier made a considerable pause, in which the ice-front lay near the line of the center ridge of this island. The southernmost point occupied by the ice-front during this division *of the period* was near the portion occupied by the sections shown in



VIEW OF COAST ESCARPMENT, 500 YARDS NORTH OF SANKATY LIGHT.

Figs. 10 and 11. The section shown in Fig. 12 lies about four hundred yards south of the morainal accumulations.

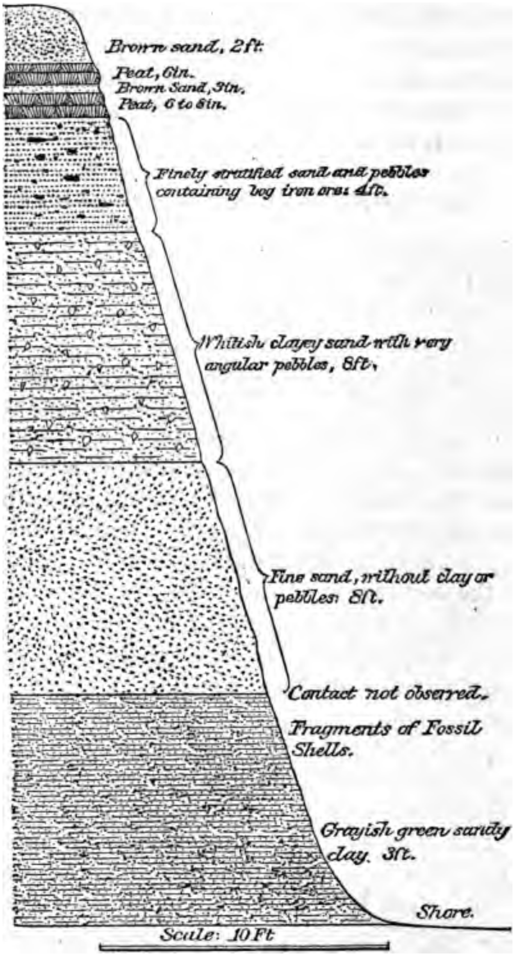

Brown sand, 2ft.
Peat, 6in.
Brown Sand, 3in.
Peat, 6 to 8in.
Finely stratified sand and pebbles containing bog iron ore: 4ft.
Whitish clayey sand with very angular pebbles, 8ft.
Fine sand, without clay or pebbles: 8ft.
Contact not observed.
Fragments of Fossil Shells.
Grayish green sandy clay. 3ft.
Shore.
Scale: 10 Ft

FIG. 12. Section south of beds at Sankaty Head.

In my opinion the history of this Sankaty Head section is as follows: After the first advance of the ice and its subsequent retreat, a movement which left the underlying till of the island in its present position, there was a considerable period in which this part of the shore was occupied by the sea. During this time the Sankaty beds were deposited, the sea shore probably sinking as they were formed; when, with the readvance of the ice, the organic life was expelled from these waters and the terrace deposits were formed above the level of the fossil-bearing beds. The passage from the obliquely stratified to the horizontal drift is so sudden that it must be taken to indicate a rapid change in the conditions which prevailed on the sea-shore at this point. This horizontal stratified drift, which contains no fossils, is capped on the top by irregular patches of bowlder material, which seem to me to be essentially till-like and to indicate that after the period of the fossil-bearing sands the glaciers again eroded this surface. It is, however, likely that only the extreme and thin edge of the ice attained to this point in its re-advance. This description of the section at Sankaty Head applies to the higher part of the cliff alone; a little to the southward the section changes greatly, as is shown in Fig. 12.

SUCCESSION OF GEOLOGIC EVENTS.

We are now in a position to consider the general history of this island during the Glacial Period, the only chapter of the geologic record which we can trace in its structure. First in this history is the series of events which led to the formation of the blue, pebbly clay or till, which, as before shown, appears to underlie the island, though it occasionally rises above the level of the sea. This deposit apparently must have been formed during the stage of the Glacial Period when the ice sheet was over this section. The unstratified nature of the mass compels us to believe that it was formed as ground moraine beneath the surface of the ice sheet, or immediately in its front. There is no evidence that this deposition continues to any distance south of the present shore of the island, but the occurrence of the mass on the ridge between the branches of Hummock Pond makes it clear that it extends about as far south as the southern shore. It does not appear possible to determine whether this region was above or below the level of the sea when this deposit was formed.

After the deposition of this mass the ice sheet retreated from the district and the climatal conditions became such as admitted the return of the marine life to the shore line, which must have been near its present position. This was certainly the case if the broken shells and coarse bedded sands at Sankaty Head be properly taken as evidence of sea-shore action. The level of this shore at one time must have been at least fifty feet below the present high tide mark. This condition in which the region was reoccupied by a marine life must have continued for a considerable period. After the fossiliferous beds were formed the ice again advanced until its southern front came at least to the middle of the island. The first result of this readvance of the ice was to erode the surface of the till and of the stratified deposits which had been formed above it. At certain points, probably over the greater part of the district, the beds were eroded all the way down to the till, as for instance at Pocomo and at some points in the center of Nantucket village. At other points, as on the north shore near the water-works, the stratified clays, which rest directly upon the till and which were probably deposited while the retreating ice front was still near the island, were not altogether removed by the later incursion of the ice.

At Sankaty Head, where the ice appears to have acted with much less energy than on the north shore, the fossiliferous beds, which doubtless lie at a considerable height above the surface of the till, and the stratified clays and sands, which normally covered it, were not removed, though they doubtless lost a portion of their thickness. As a result of this erosion by the second advance of the ice the beds containing the fossils, which possibly at one time covered the whole of the island, were left as separated patches.

During this readvance, or, perhaps, in several successive readvances, were accumulated the existing heaps of stratified and amorphous sand, gravel, and bowlders as well as the southern sand plains which constitute the principal features of the island. The conditions of their accumulation are, as far as determinable from the evidence, as follows, viz:

(1) The surface was below the present level of the sea. This is shown by the fact that there are no drainage channels leading out of the many valleys between the sand hills, such as would have been formed if the masses had been accumulated above the level of the sea, as are moraines at the front of a land glacier, as well as by the numerous bowlders apparently dropped from icebergs.

(2) The drift materials were partly shoved forward by the glacier and partly deposited by the streams which escaped from beneath the ice. This is shown by the intermingling of confused or amorphous drift with large bowlders and with stratified deposits of fine sands.

(3) The existence of considerable streams rising from the ice front and extending to the south is shown by the numerous deep channels which are excavated in the southern terrace or sand plains. These valleys originate in the hills and extend southwardly as distinct channels. They are comparable to the channels which are cut through sand deposits below the level of the water at the mouth of estuaries where considerable streams escape into the sea. It should be observed that all these valleys do not clearly head up against the base of the sand hills, though all of them trend in that direction. It appears likely, from what we know of the tendency of subglacial streams to change their position, that all of these streams may not have been flowing at the same time; indeed, they may have been made in succession by the changing direction of a few of these rivers which emerged from beneath the ice. The irregular accumulation of débris near their points of escape from beneath the ice sheet would of itself have a tendency to direct these streams to new channels. Clearly, we can not suppose that these channels were formed after the ice left this region, for there is no form of water action disconnected with glaciation which can be imagined to have produced them.[1]

(4) The sand plains on the southern part of the island, which exist nowhere else upon its surface, were deposited during the time when the

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[1] Geology of Martha's Vineyard: Seventh Ann. Rept. U. S. Geol. Survey.

do not contain any such mass of débris as would have been swept into them by this process. It is true that the bottoms of the depressions often contain a small amount of sand, such as could be washed into them by torrential rains. These deposits are not disposed in the form of a flat-surfaced mass of stratified sand and gravel, as would have been the case if they had been formed by ocean waves, but they are made of fine sand which slopes gently toward the center of the pit. (See Fig. 14.)

In a word, we can not believe that ridges of sand and gravel, with the accompanying sand plains, having the delicacy of outline which marks the contours of these great morainal accumulations could have been formed except beneath the sea. We are also forced to the conclusion that these deposits escaped from the water through the surf by a very sudden movement. In a report on the geology of Mount Desert, Maine,[1] I show that we have other evidence leading to the conclusion that the recovery of this shore from the deep subsidence that attended the Glacial Period was extremely sudden.

At this point we may discuss the peculiar compass course of the Nantucket moraines. So far as we can determine the matter the front of the ice during the formation of the Nantucket moraine lay in a nearly east and west direction. The exact alignment is not determinable from the direction of the separate mounds of drift, which are too isolated and irregular to afford any indication of the movement of the glacier. But considering these morainal masses as a topographic whole it is clear that their extension is within 5° of an east and west direction. This course is a wide departure from that of the other similar moraines of this district. The Elizabeth Islands frontal moraine has a nearly northeast and southwest trend, both in the islands whose name I have given to it and in its obscurer extension on the mainland of Cape Cod. It preserves this northeast and southwest course for a distance of over 40 miles without showing at any point a departure of more than 8° from the average direction of the line. The older moraine on the northern shore of Martha's Vineyard, although much shorter, evidently has the same direction. So far as I have observed, the moraines on Cape Cod, which, it is true, are very fragmentary, have the same general alignment.

On the other hand, the moraines of Long Island, New York, have a general course which is intermediate between those just noted and that of Nantucket. Their course is about N. 70° E. and S. 70° W. It is thus evident that there is a considerable range in the direction of these frontal moraines within 200 miles of distance on the southern shore of New England.

The wide difference between the direction of the ice front on Martha's Vineyard and that on this neighboring island of Nantucket may be due either to the existence of a great loop in the ice front at this point or to the fact that this Nantucket moraine, being the outermost of the frontal

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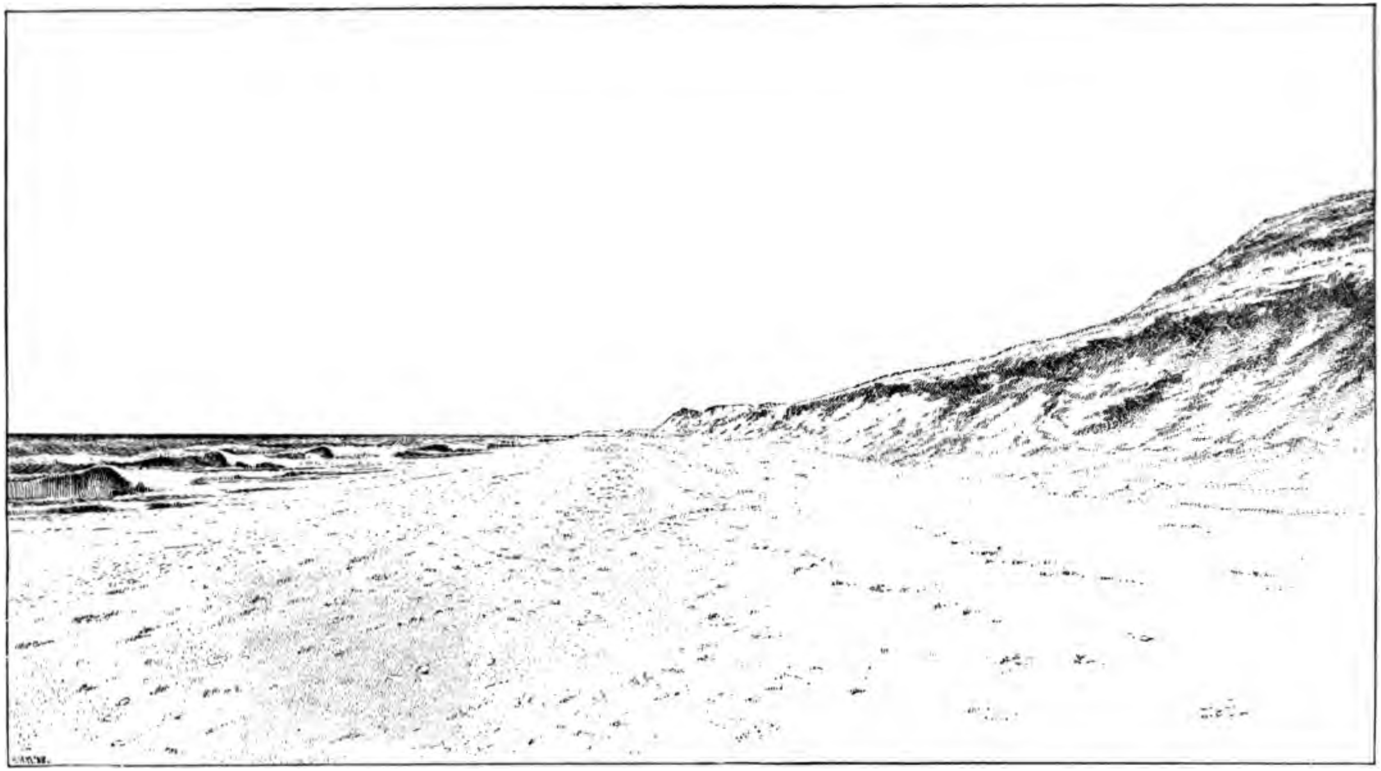
[1] Eighth Annual Report U. S. Geol. Survey.



ASPECT OF NORTH SHORE FROM NEAR UPPER END OF LONG POND, LOOKING EAST.

deposits on this part of the continent, had a direction different from the later formed moraines on Martha's Vineyard and Elizabeth Islands.

The existence of such great loops in the frontal moraines has been made clearly evident by the labors of Professor Chamberlin and his assistants in the northern part of the Mississippi Valley. They may be therefore reckoned upon as possible accidents on all parts of the ice front. So far, however, I have not been able to reconcile the facts presented by the Nantucket moraine with the hypothesis that it is a part of a loop in a frontal moraine of normal direction. There is no trace of curve in its considerable length and it is not possible to connect it with any of the existing moraines by any hypothesis of form which I have been able to apply to it. Moreover, there is the important fact to be considered that we have as yet no evidence of any loops in the moraines in this part of the continent. In favor of the view that it is the fragment of a moraine older than any other occurring along this part of the coast, we have the important fact that the pebbles are much more decayed than they are in any of the morainal accumulations which lie to the northwest of it. It may reasonably be asserted that this difference in the measure of decay amounts to as much as one-half of the total oxidizing action which has been applied to this drift material.

The difference in orientation of this and other moraines may possibly be explained by the supposition that in the time when the glacier had its furthest extension, the movement of the ice was along the north and south line; while when the ice began to retreat the direction of the flow was gradually changed, the movement in the end being from the northwest. There is a good deal of evidence to support this view which can only be suggested in this memoir. The most important part of this evidence is found in the direction of the troughs excavated by the ice during the glacial period. These troughs probably owe their formation in the main to the force exerted in that part of the glacial epoch when the ice was deepest. The general trend of these troughs is from north to south. Although the cutting action which formed this valley has been in part guided by the positions of the rocks, that is, by their strikes and dips, it is clear that it was more generally determined by the direction of the ice movement. I therefore think it possible that the ice during the period of its greatest extension moved in a more meridional direction than during the period of its decline.[1]

POST-GLACIAL CHANGES OF NANTUCKET.

We shall now consider the changes which have taken place in this district since the last retreat of the glacial ice. These changes may be grouped under three heads, viz, changes of level, changes due to the alteration of the surface, and changes due to the wearing action of the sea.

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[1] I venture in passing to call attention to the fact that this change in direction may be due to the very great extent to which the ice overlapped the shore during the time when it was thickest, when it probably had its front far out on the relatively level surface of the continental submarine shelf. It probably moved southward rather than toward the deeper sea on the east. As it shrunk, the eastern movement became more evident.

The principal change of level was that which brought the sand and gravel hills and the fringe of lower land on the south above the surface of the sea. The amount of this elevation can not be accurately determined, at least from the evidence afforded by this island; still we may fix the minimum amount of the change in a rough way. Assuming that the sand hills were formed on the sea-floor at the front of the ice, we must suppose that they were originally at a depth which protected them from the action of the ocean waves. This requires us to suppose a submergence of their summits to a depth of at least 200 feet below the level of the sea, and even at that depth it is difficult to see how their easily moved sands remained undisturbed by the waves of great storms, which at the depth of two or three hundred feet produce a considerable motion in the water. As the highest of these sand hills now lies about 90 feet above the level of the sea, it is evident from our premises that the post-glacial uplift was not less than 300 feet and may have been much greater. This estimate, it may be remarked, is quite consonant with the evidence which is afforded by the other parts of the shore in this district.

After the first elevation there came at least one other movement of this shore, this time in a downward direction, which brought the fresh-water peat deposits beneath the sea-level. This last movement possibly did not change the level of the land to more than ten feet of altitude, though the alteration may have exceeded this amount.

There is another feature in the structure of the island which seems to afford some evidence of the recent subsidence of the shore. It will be seen from the map that the portion of the northern shore of the island which lies inside of Coatue Beach has a very indented shore-line, while the coast to the west of the harbor has a shore which has the outline proper to all coasts where soft materials have been subjected to the long continued action of the waves. The interpretation of this peculiarity seems to me to be as follows, viz: This shore after the post-glacial elevation must have been much farther to the northward than it is at present; then came the subsidence indicated by the submerged peats, as before described, which brought the land to about its present level. The beach of Coatue was rapidly formed in front of a portion of the north shore, and has since served as a protecting barrier against the assaults of the vigorous waves which form in Nantucket Sound. If this part of the shore had long been exposed to the action of the open water it would certainly have a different contour from that it now exhibits. The failure to form a similar barrier along the shore to the west of the harbor is probably due to the originally deeper water on that part of the coast, or to the absence of the supply of detrital material necessary *for the formation* of a barrier beach.

It must remain an open question whether these last described elevations and subsidences were local or general in their nature, or, in other words, whether they are in consequence of a general continental movement or were due to forces affecting only the district in which the island lies. Still further we are left in doubt whether these changes in level were of equal amount in all parts of the island. A comparison of the evidence attainable in this area with that which may be found on other parts of the neighboring land must be made before these points can be decided. So far as I have been able to compare the facts with those which are evident on the shores of Martha's Vineyard, the following results only have been found: On that island, as set forth in my memoir in the Eighth Annual Report of the U. S. Geological Survey, conclusive evidence of extensive subsidence is wanting. The conditions there are unfavorable for the preservation of such evidence. Still, we note the fact that on both these islands there is a remarkable correspondence in the height of the southern glacial plain above the level of the sea; in both islands the altitude of the southern escarpment along the Atlantic shore is essentially the same, and the channels which extend from the frontal portion of the moraine to the sea are about the same height above the tide-level. If there be any difference it is that these channels on Nantucket are at a slightly lower level than those on Martha's Vineyard. On the assumption that these frontal aprons were originally formed at the same height, the island of Nantucket has not been lowered more than 10 feet below the level to which the southern shore of Martha's Vineyard has attained since the close of the Glacial Period. It is not positively certain that these frontal aprons were originally formed at the same depth beneath the sea, yet the equal elevation of these two fragments of the coast is, considering the small distance which separates the two islands, a fair basis for believing that they were formed at about the same depth beneath the sea, and that they have since retained their positions relative to each other during the process of elevation which brought them to their present altitudes.

RECENT CHANGES ON THE COAST OF NANTUCKET.

The recent changes on the coast of Nantucket have a special interest, for the reason that they include some very curious horizontal modifications. (See Pl. IX.) While the larger part of the coast of Martha's Vineyard is now wearing away with considerable speed, rather more than the half of the periphery of Nantucket is at the present time not only exempt from wear, but exhibits a gradual accretion (Fig. 15). The gain of land on the sea is at present most conspicuous on the southeast section of the shore from Tom Never's Head to Siasconset. Along this portion of the border of the island the sea no longer attains the bluffs at any point, being shut out from them by a strip of sand which forms the crescent-shaped apron extending, at its widest part, about one-third of a mile from the shore. These sands have apparently been derived in part from the erosion of bluffs to the north and west of the site where they are accumulated, but perhaps in larger measure they may have been washed in from the floor of the sea. The formation of this extensive deposit appears to indicate a recent change in the regimen of the currents along this part of the coast; for it is evident that the coast-line was rapidly working inland until this apron began to form. It has evidently been but a short time since the sea beat against the cliffs inside of this protecting accumulation. These cliffs retain in good part the original shape given them by the erosive action of the waves. I have not been able to obtain any satisfactory information as to the growth of this apron within the historic period, but I am inclined to believe that it has been largely, if not altogether, formed since the settlement of the island by European population.

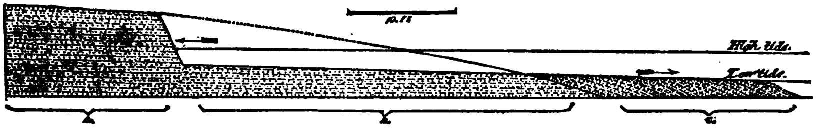
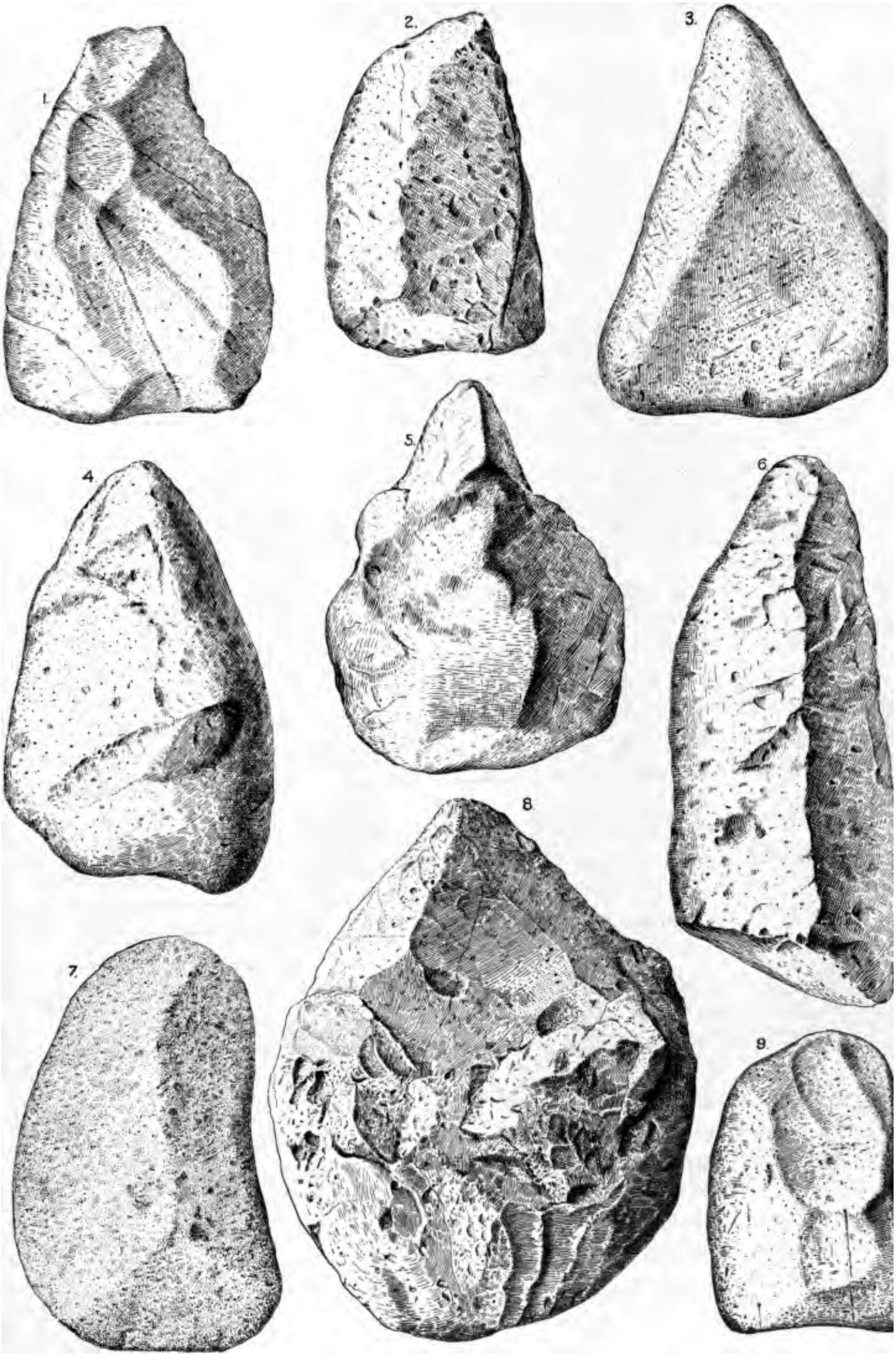


Fig. 15. Section of shore east of Surf Side.

I have also been unable to determine the nature of the alteration which led to the construction of this apron. The currents of these waters depend upon so many conflicting conditions that it does not seem possible at present to say to what this change is due. It appears, however, to have been connected with an alteration which seems to be now going on in the channels immediately to the eastward of Siasconset. It is a common opinion among seafarers of Nantucket that this channel is now less obstructed by sands than formerly; at present, ships venture through this passage, where of old, on account of its shoals, they did not dare to sail. If we may assume that such changes in this channel have really occurred we might suppose that the greater scour of the tidal currents in this water has removed from the bottom of the channel a quantity of sands and accumulated them in this shelf, which would afford not unnatural lodgment for them. It is evident that this apron of sand is extending its extremities to both the north and west. In the former direction it is affording some protection to the steep bluffs at Sankaty Head; although yet not a complete barrier to the action of the sea, it has diminished the wear on the shore bluffs in a noticeable way. Within a few years this escarpment has become in part grassed over. To the westward this apron is extending with considerable rapidity, as is indicated by the fact that the bluff still retains the marks of sea action at points where it is now completely defended by the protecting apron.

Another region of extensive accumulation in very modern times is that part of Great Head which extends from the apex of the triangle in *which lies Croscaty* Pond and forms a remarkable promontory (Fig. 16).



SPLIT PEBBLES, RESEMBLING STONE IMPLEMENTS.

This accession is evidently of less recent origin than the Siasconset apron. It consists of extensive sand dunes and beaches, the sand of the dunes having been borne to them by the winds. Although these dunes are frequently much wasted by the action of the same force which brought them to their present position, they are still very remarkable examples of wind blown sands. The extremity of this cape is now separated by a channel having about four fathoms of water at mean low tide from the point of the rip shoal, on parts of which there are not over four feet of water at low tide. Within the last century the extremity of this cape has fallen back southward for the distance of 1,400 feet, as noted by Prof. Henry Mitchell. This recession of Great Point has probably been a consequence arising from the rapid extension of the promontory of Monomoy, which, according to his determinations, has extended southward two miles during the past century.[1] It is possible that a portion of the material wasted from this point has been contributed to the Siasconset apron.

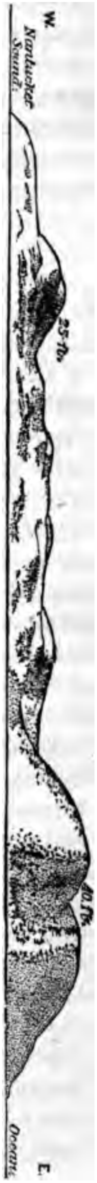


FIG. 16. Profile across Great Head, showing dunes.

The most extensive of these modern contributions to the shore of Nantucket is found in the mass of Coatue Beach, which contains a larger body of recently drifted sands than all the other similar deposits found along the shores of this island. If we consider the submarine portion of this peninsula as well as the emerged part we find it to contain a mass about equivalent to a layer a hundred and fifty feet deep occupying a square mile of area. A part of this material appears to have been derived from the bottom of Nantucket Bay by the action of the waves; a portion of it may have come from the recession of Great Head.

About one-third of the coast-line of Nantucket appears now to be undergoing erosion. At the eastern extremity of the island the erosive action appears at present to be limited to the section from the southern end of the Sankaty bluffs to a point just beyond Haulover Beach at the head of Coatue Bay. In 1873 Prof. Henry L. Whiting found by a resurvey of this portion of the shore that the eastern or sea side of the coast at the Haulover had receded by an average of about one hundred feet since 1846. Between Sachacha Pond and the Haulover, especially at Squam Head, the wasting is evidently at this day quite rapid, probably amounting to at least a foot a year.[2] The southern coast westward from Tom Never's Head, especially the section west of

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[1] Monomoy and its shoals: Annual Report of the Harbor and Land Commissioners of Massachusetts, Boston, 1887, p. 42.

[2] Report of Harbor Commissioners of Massachusetts, 1873, p. 109.

Weedweeder Shoal, is also the seat of a considerable, though apparently inconstant, wear. A remarkable but probably temporary change has recently taken place in the long spit which forms the western extremity of the island as it is delineated on the Coast Survey maps. Twenty years ago this spit at low tide constituted an almost complete bridge extending from Nantucket to Tuckernuck Island. Of recent years this point has in good part been washed away almost down to its base near Further Creek. It seems possible that the existing separation of Tuckernuck from Nantucket may have been brought about by the action of marine currents within a relatively short time.

VEGETATION OF NANTUCKET.

The present condition of the flora of this island deserves some notice in this memoir, for the reason that it throws light upon its geological history. At present this is the most treeless area on the eastern coast of the United States. There are no traces of original forest upon its surface. About the borders of the smaller ponds, especially where these pools are well sheltered by the kame hills, there are a few stunted oaks and other forms of our ordinary New England trees, but in no case do they give the conditions of a forest. None of the specimens of this natural growth exceed 20 feet in height. On certain parts of the central region of the island artificial plantations of pines exist, but the trees, though in some cases nearly half a century old, have never attained a height of more than 20 feet and survive with difficulty, in the existing conditions of the climate and soil. Although the greater part of the surface of the island has remained entirely wild there is no trace of a tendency to return to the condition of forest.

There is a tradition, not, so far as I have been able to find, supported by any trustworthy records, that this island when first occupied by the European settlers was generally forest-clad, and that the trees of oak and pine were sufficiently large to afford ship-timber as well as material for edifices. Those who have had occasion to examine traditions as to the nature of forest-covering of a region now deprived of trees, know how untrustworthy such reports frequently are. At a number of points along the eastern shore of the United States where the poverty of the soil is very great and the timber extremely stunted we hear the same vague account of vanished woods. Nevertheless, though such traditions are open to suspicion, I am inclined to believe that when this island was first settled the greater part of its surface, at least that portion of the area north of the southern plains, was covered with a forest growth which afforded some architectural timber. As soon as this covering was removed, as it was before the middle of the last century, without any effort to restore its forest coating, the soil came to its present treeless state.

The failure of these woods to recover possession of the earth demands an explanation. This explanation we may find in either of two ways. We may suppose that there has been in modern times a change in the climatal conditions affecting this portion of the continent which makes it impossible for forests to be reestablished. Or we may account for the nudity by supposing that in the earlier day the island was very much more extensive than it is at present and that the climate was so far locally modified by the greater land area that the timber was enabled to gain a foot-hold. This latter supposition appears to be the most consonant with the known facts. It seems to me tolerably clear, from the topography of Nantucket as well as that of the sea-bottom north and south of it, that the island has not lost much of its surface for a considerable time in the past; but if we go back to the time when the last subsidence of this shore took place—the subsidence which lowered the peat deposits before mentioned below the level of the sea—we may be able to assume a reduction in the area of the land resulting from that down-sinking sufficient to account for the required change of the climatal conditions.

That there has been a general change of climate on this part of the continent sufficient to account for the failure of these woods to repossess the surface of the island appears to me an unreasonable assumption, because on the mainland we find no evidence of such a modification of climatal conditions. I am, therefore, disposed to believe that the forest-covering of Nantucket was established at a time before the last subsidence of the shore, and that this subsidence so far reduced the area of the land that the well-known influence of the sea air penetrating to the central portions of the island served to prevent the restoration of the timber after it had been removed.

The present flora of Nantucket, though it wants the larger trees, is extremely rich and varied. The absence of a forest-covering has enabled a host of low-growing plants to establish themselves upon its surface and to develop with a luxuriance which they do not attain on the mainland. The interaction of these plants in their unwonted freedom of development affords many problems of interest to the botanist which deserve more attention than they have yet received. It would be particularly interesting to consider the differences in the vegetation determined by the peculiarities of the soil in the various parts of the island, were it not that these problems lie beyond the scope of this report. I venture, however, to note for further inquiry on the part of those who may take up the question, that the differences between plants growing on the sand hills on the southern plains and in scanty areas of clay soil which exist on the surface of Nantucket are very great; and, furthermore, that very large areas of the southern plains, where the soil is composed in the main of quartzose sand, are occupied almost exclusively by mosses and lichens.

A peculiar feature in the botany of the island is found in the presence of cacti in the region north of Coatue Sound. Along Coatue Beach and in the district about Croskaty Pond, as well as on Great Head, one or two species of *Opuntia* are extremely abundant. This is certainly the easternmost and possibly the northernmost station in the region east of the Appalachians attained by any part of this interesting group of American plants. I have been unable to ascertain when this form appeared upon the island, whether it has been introduced by human agency or has come to its position in a natural way. It seems clear that it has been upon the island for a long time. If it be true that there are two distinct species present on this shore, then it is most likely that the introduction took place in the natural way. The field now occupied by these cacti has a length of about four miles and a width near Croskaty Pond of about a mile. It is a singular fact that, although within this area the plants abound and apparently find the circumstances well suited to their needs, the species has not extended to the southern portions of the island. Apparently the great beach apron at Siasconset affords a site equally well suited to these plants, but a careful search of this field, made in 1875, failed to show a single specimen of the genus upon it. Within the field occupied by these cacti they never depart from the areas of blown sand. The hummocks of kame drift which rise within this field do not seem to afford conditions for their development.

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